

GENERATION OF ELECTRIC POWER AND THERMAL ENERGY FROM CONTAMINATED BIOMASS INTEGRATED WITH STRINGENT ENVIRONMENTAL POLLUTION CONTROL

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ABSTRACT

Prior to the so-called "oil crisis" in 1973, energy generation from virgin or waste biomass was of limited interest. In the interim, energy costs and adequacy of waste management means have grown in importance.

Moreover, air pollution legislation and scarcity of landfill disposal capacity have further emphasized the role of integrated energy and waste management.

This paper details a newly developed process application in Germany, now successfully installed, commissioned and in full commercial operation that combines modern firing technology with high-efficiency combined flue gas treatment.

1. INTRODUCTION

Ultimate disposal of millions of wooden railroad ties, principally from abandoned lignite mines, has for years been awaiting a technology that permits contaminated biomass, especially wood based waste, to be combusted in compliance with Germany's stringent environmental pollution control regulations.

Waste-to-energy plants, incinerating municipal waste have often rejected this type of combustibles due to its high net calorific value (N.C.V.), while common landfills have been unable to accept the wood waste due to its leachable constituents and the resulting risk of groundwater pollution.

There have been several trials of combustion of such wood waste, i.e. railroad ties, telephone poles, etc. in conventional incineration plants by mixing it with natural wood, but they have not been fully acceptable.

The plant described in this paper is designed exclusively for combustion of contaminated wood waste. "Wood waste" has a wide-ranging definition. It includes structural timber, railroad ties, telephone poles, wooden poles from vineyards and hops cultivation, window frames, laminated particle board (with HCl-containing compounds in the laminates), bulky refuse items and other waste wood from the woodworking industry. Each of these types of wood is often contaminated because of coating or impregnation.

The purpose of the WULFF-designed incineration plant fulfilled in commercial operation beginning in 1998 and detailed herein is:

- to dispose of this wood waste with recovery of its energy content so as to be ecologically beneficial,
- to render waste contaminants harmless by combustion,
- to dispose of or utilize the combustion residues (grate ash and fly ash) in an environmentally acceptable manner consistent with laws and regulations,
- to clean the flue gases of harmful polluting substances in accordance with governing legislation, in this case the German environmental standard applicable to the combustion of waste material (17. BImSchV).

In advance of the construction of the plant extensive project planning was carried out, including preparation of many expert reports, such as fuel analyses, environmental impact studies, etc.

Table 1 shows the timetable of the entire project in summary form.

2. PROCESS DESCRIPTION

The plant described in this paper includes two principal processes: a) fuel preparation and b) combustion combined with flue gas cleaning. The wood waste is delivered by truck or by train from its sources : the mining industry, railroads and construction and demolition firms. The individual types of wood waste are stored separately on site before being crushed and otherwise prepared for combustion. Typical inventory is sufficient for about three weeks' operation.

2.1. Preparation of the fuel

Mechanical preparation of the fuel prior to combustion comprises:

- mechanical pre-crushing by a slow-speed disintegrator
- separation of magnetic material
- mechanical crushing to the required fuel size
- separation of glass, ceramics, nonferrous metals, etc.
- wafering of fines (i.e. 2 x 2 x 2 in.)
- storage in concrete bins and in a day-bin.

Separation stages are intended to achieve 98 % removal of glass, ceramics, nonferrous metals and magnetic material. Figure 1 presents a flow diagram of the entire process. The prepared fuel, which has an average size of 60 mm (2 in.), is conveyed into a day-bin which is charged with formulated mixtures. This fuel blending takes into account the principal various pollutants in the different types of wood waste so as to establish defined mixtures.

TABLE 1: ABBREVIATED PROJECT TIMETABLE

Beginning November, 1994	Basic engineering and planning phase
Beginning September, 1995	Technical concept evaluation and project phase
September, 1996	Receipt of order
April, 1997	Start of erection
December, 1997	Mechanical erection completed
January, 1998	Functional test runs
February, 1998	Start of commissioning
April, 1998	Start of firing
July 15, 1998	Test runs completed
Beginning July, 1998	Commercial operation of the facility by the client

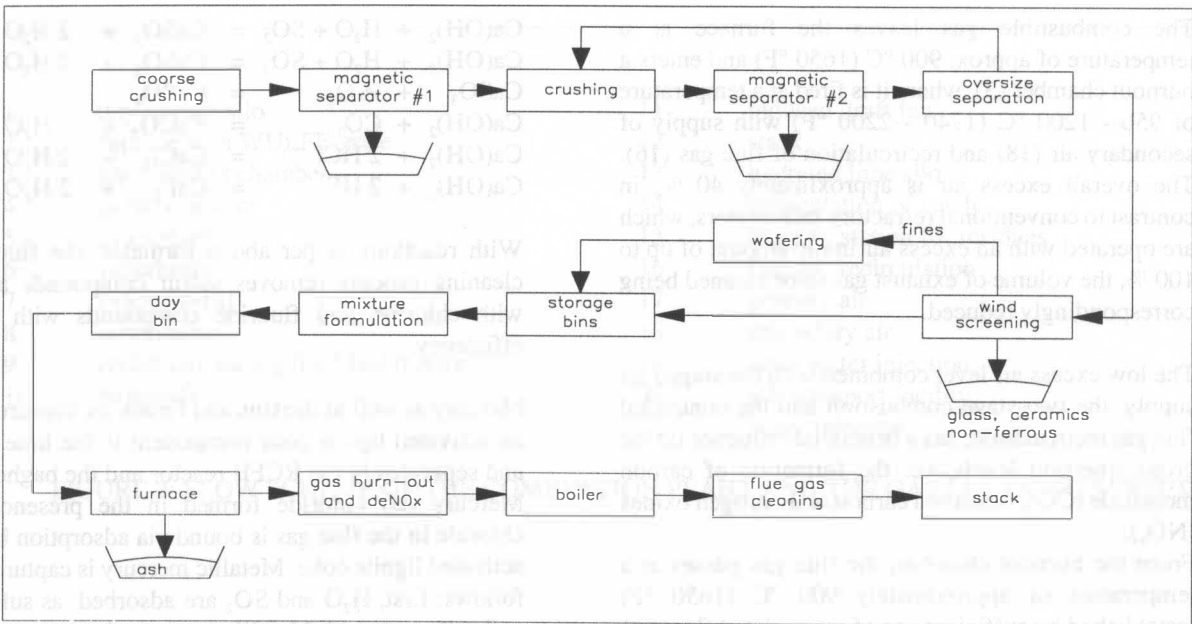


FIGURE 1: FLOW DIAGRAM OF THE FULL BIOMASS WASTE PROCESS

2.2. Combustion and steam generation

The complete combustion process including the boiler and the flue gas cleaning facilities is shown in Figure 2, following the flue gas path.

Referencing the numbering system in Figure 2, the fuel, taken from the day-bin (1) and transported to the furnace by a vertical conveyor and a weighbelt feeder, is fired on an inclined movable grate (2) in conjunction with primary air feed (17) and recirculation of flue gas (16) forming fuel gas. The oxygen supply (the oxygen contained in air supply and recirculated flue gas) is adjusted so as to generate a burnable gas. The inclined movable grate is divided into a series of sections to provide individual air supply to each sub-process along the grate (drying, degasifying, gas generation, combustion, and burnout of the ash) that meets the respective oxygen requirement. Each section is equipped with a hydraulically driven grate carriage that is operated at an individually adjustable speed to control the rate of reaction of the fuel.

The combustible gas leaves the furnace at a temperature of approx. 900 °C (1650 °F) and enters a burnout chamber (3), where it is fired at a temperature of 950 - 1200 °C (1740 - 2200 °F) with supply of secondary air (18) and recirculation of flue gas (16). The overall excess air is approximately 40 %, in contrast to conventional refractory incinerators, which are operated with an excess air in the amount of up to 100 %, the volume of exhaust gas to be cleaned being correspondingly reduced.

The low excess air level combined with the staged air supply, the two-stage combustion and the controlled flue gas recirculation, has a beneficial influence on the gross emission levels, i.e. the formation of carbon monoxide (CO), unburned carbon and nitrogen oxides (NO_x).

From the burnout chamber, the flue gas passes at a temperature of approximately 900 °C (1650 °F) (established by sufficient use of recirculated flue gas) into the deNO_x reactor (4), where it is treated via urea reagent (19) to reduce the NO_x content; this step is specified and required if the nitrogen content of the fuel is exceptionally high.

The water-cooled preheating chamber of the water-tube boiler, constructed with finned-tube waterwalls, contains the first evaporative heating surfaces (5). The superheater (6) heats the saturated steam to approx. 360 °C (680 °F). The second boiler pass provides a second stage of evaporative heating surfaces (7). The

two-stage economizer (8) cools the flue gas to approximately 160 °C (320 °F).

The steam production is available to drive a condensing turbine or to supply an existing steam distribution system.

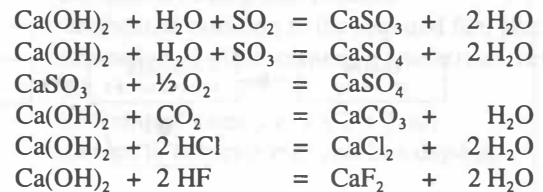
The flue gas used for recirculation (16) is drawn from between the economizer outlet and the inlet of the flue gas cleaning facility.

2.3. Flue gas cleaning process

A semi-dry flue gas cleaning process wastewater free and based on a Reflux Circulating Fluid Bed (RCFB) reactor as absorber is used optimally to remove diverse pollutants.

Chemical reactions

The following simplified reactions play a key role in flue gas cleaning system in the temperature range 60 - 180 °C (140 - 360 °F):



With reactions as per above formulae, the flue gas cleaning process removes sulfur compounds along with chlorine and fluorine compounds with high efficiency.

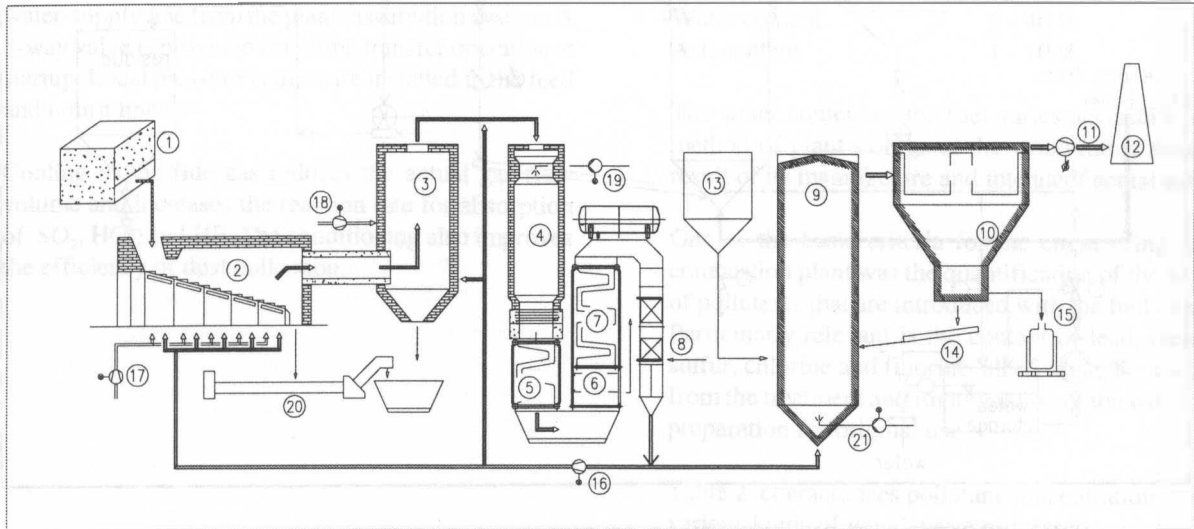
Mercury as well as dioxins and furans are captured by an activated lignite coke component in the lime feed and separated in the RCFB reactor and the baghouse. Mercury (II) chloride formed in the presence of chloride in the flue gas is bound via adsorption by an activated lignite coke. Metallic mercury is captured as follows: first, H₂O and SO₂ are adsorbed as sulfuric and sulfurous acid. Metallic mercury then reacts with the adsorbed sulfuric acid, forming mercury sulfate:



Gas route (see Figure 3)

After passing through the boiler, the flue gas enters the RCFB absorber centrally from below and moves in turbulent flow therein along with the hydrated lime feed and the internally refluxing reaction products to the top section of the absorber.

The gaseous pollutants are collected in the RCFB by sorption on hydrated lime and on the unused hydrated lime component of the residue recycled from the baghouse.



- | | | | |
|----|--------------------------------------|----|------------------------------|
| 1 | day storage silo | 11 | induced draft fan |
| 2 | furnace with WULFF-grate | 12 | stack |
| 3 | gas burn out chamber | 13 | hydrated lime silo |
| 4 | deNOx-reactor | 14 | recirculation of catch |
| 5 | evaporizer I | 15 | bagging station for residues |
| 6 | superheater | 16 | flue gas recirculation |
| 7 | evaporizer II | 17 | primary air |
| 8 | economizer | 18 | secondary air |
| 9 | reflux circulating fluid bed reactor | 19 | urea/ water injection |
| 10 | baghouse | 20 | ash transport facility |
| | | 21 | water injection |

FIGURE 2: FLOW SCHEME OF THE COMBUSTION PLANT AND THE GAS CLEANING SYSTEM

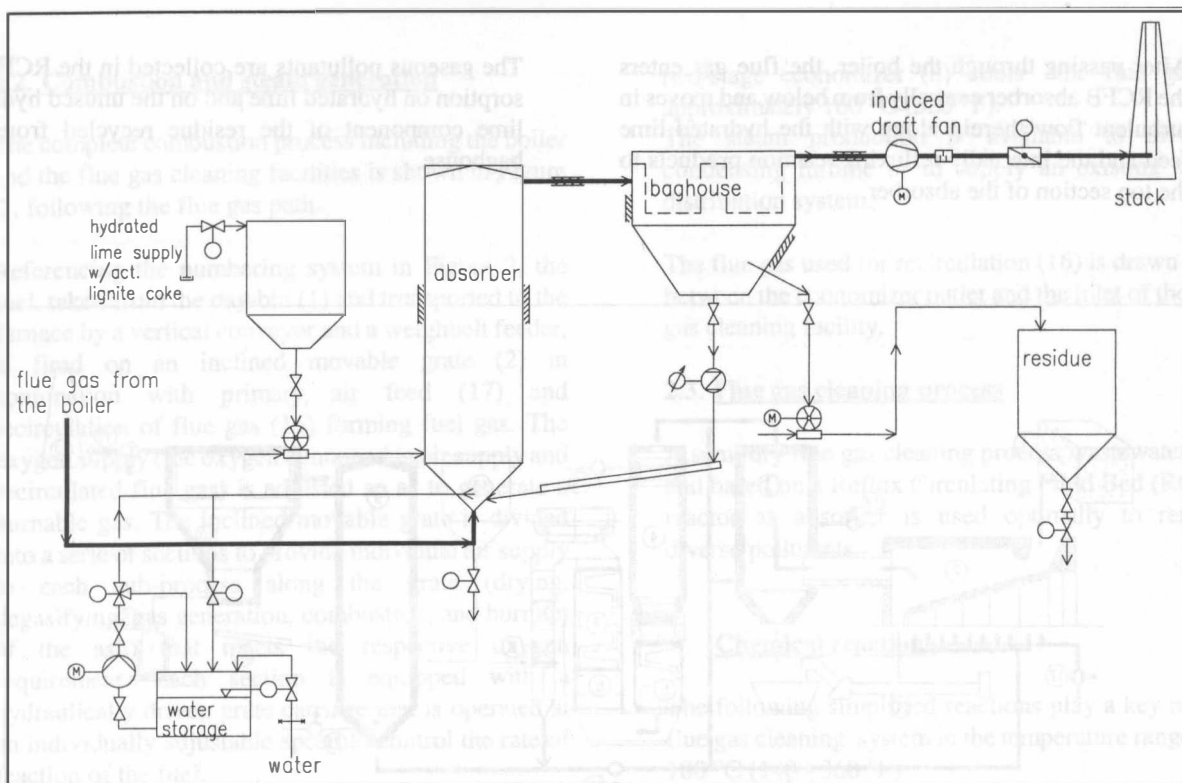


FIGURE 3: FLOW SEQUENCE OF THE FLUE-GAS CLEANING FACILITY

The flue gas is cleaned of acid gases in the RCFB absorber according to the reaction equations listed above, leaves the top of the absorber as a gas/particulate mixture and enters the baghouse, in which the solids content is reduced to less than 10 mg/Nm³. The gaseous pollutant contents are further reduced within the baghouse at the same time.

The cleaned flue gas enters the stack via the ID fan and the flue gas breeching. The flue gas cleaning operation can, in an emergency, be bypassed by means of a separate duct. The bypass duct is purged with atmospheric air when not in use.

Solids flow routes in the flue gas cleaning plant

The hydrated lime/activated lignite coke mixture for flue gas cleaning is transferred from a hopper truck equipped with its own conveying system to a lime storage silo, from where it is pneumatically injected into the absorber. The storage silo has level indicators giving indication of minimum and maximum. When the discharge valve of the silo is opened, the hydrated lime is fed into the RCFB absorber. Control of the discharge rate is governed by measured emission levels.

The fine particulate matter (lime, hydrated lime and residual fly ash) introduced into the RCFB absorber is conveyed, after solids capture and an appropriate residence time in the baghouse, to an insulated, fluidized, temporary storage bin forming an integral part of the filter. With the recirculating valve of the temporary storage bin in the open position, a large proportion of the material is fed into the solids recirculation system for return to the RCFB absorber.

The quantity of particulates recirculated is controlled in accord with the differential gas-streams pressure, measured between the inlet and the outlet of the RCFB absorber.

The particulates are discarded from the fluidized temporary storage bins via overflow to a bagging station. The storage bins are emptied when necessary by opening a shut-off valve at the bottom of each bin. (There is an additional particulates discharge point beneath the RCFB absorber.)

Conditioning of the flue gas

The flue gas is cooled by evaporation of atomized water. The water feed rate is controlled in accordance with the selected reactor-temperature setpoint.

Atomization is by means of a specially developed, high-efficiency spray nozzle with water supplied by a high-pressure pump.

The water feed rate is continuously modulated by means of an electropneumatic control valve positioned in a return line. The water supply tank is equipped with a float valve for level control including a low-level alarm and with a water meter in the incoming water-supply line from the plant distribution system. A 3-way valve is provided for pump transfer operation at startup. Local pressure gauges are installed in the feed and return lines.

Cooling of the flue gas reduces the actual gas flow volume and increases the reaction rate for absorption of SO₂, HCl, and HF. The conditioning also improves the efficiency of dust collection.

3. Process requirements and peculiarities

3.1. Fuel data

The fuel mixture from the day-bin has the following average properties:

N.C.V. (net calorific value)	12 - 20 MJ/kg
Water content	5 - 40 %
Ash content	1 - 10 %.

The water content of the fuel varies according to the method of plant storage of the wood rather than as a result of its manufacture and intended/ actual use.

One of the basic criteria for the engineering of the combustion plant was the quantification of the amount of pollutants that are introduced with the fuel mixture. Particularly relevant is the content of lead, mercury, sulfur, chlorine and fluorine, all of which arise mainly from the treatment and impregnation of the wood in its preparation for original use.

Table 2 characterizes pollutant concentrations for the various kinds of wood waste processed.

TABLE 2: POLLUTING SUBSTANCES IN WOOD WASTE SUPPLY

		window frames			wooden sleepers			telephone poles		hops
		colored	white	untreated	1	2	3	coated	uncoated	poles
ash	[%]	5	3.3	1.3	2	2.9	1.9	0.3	0.3	0.9
antimony	[mg/kg]	0.6	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
arsenic	[mg/kg]	19	0.6	0.1	0.6	1.5	0.9	1.1	0.1	0.4
lead	[mg/kg]	11800	1500	78	67	37	180	46	22	26
chrome	[mg/kg]	210	22	11	27	20	56	17	6.5	24
cobalt	[mg/kg]	9.5	7.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
copper	[mg/kg]	29	10	7.1	10	29	5.7	18	11	17
manganese	[mg/kg]	110	100	90	87	78	88	100	90	170
nickel	[mg/kg]	2.7	0.9	0.7	1.3	1.9	8.6	0.4	0.6	0.9
vanadium	[mg/kg]	2	2	2	2	2	2	2	2	2
tin	[mg/kg]	28	11	0.5	0.8	1	0.7	0.4	0.7	0.4
cadmium	[mg/kg]	13	3.8	0.2	0.1	0.1	0.2	0.1	0.1	0.2
mercury	[mg/kg]	4.1	5.9	0.3	0.7	0.5	0.4	370	290	1.6
sulphur	[mg/kg]	2820	1590	1050	830	770	50	1110	470	630
chlorine	[mg/kg]	240	250	750	50	90	10	250	150	250
fluorine	[mg/kg]	100	20	40	380	930	10	20	80	10

3.2. Combustion conditions

The German environmental standard of November 23, 1990, stipulates for the combustion conditions that :

" The combustion temperature ... shall be at least 1200 °C (2200 °F). This minimum combustion temperature shall be complied with even under unfavorable conditions ... for at least 2 seconds at an oxygen concentration of at least 6 % by volume..."

This means, in the case of the WULFF system, that the combustion temperature must be higher than 1200 °C (2200 °F) immediately after the point of last supply of combustion air as well as at the outlet of the burnout zone. The retention time of the flue gas between these two points must be at least 2 seconds.

This condition has been achieved in practice in the following manner: the actual combustion zone (furnace with WULFF inclined feed grate) is followed by a brick-lined burnout chamber to which no additional combustion air is supplied. The burnout chamber basically comprises a brick-lined cylinder with a tangential flue gas inlet. High-quality fireproof brickwork ensure low heat losses.

Figure 4 provides a sectional view through the furnace and the burnout chamber.

A supplemental fuel-oil fired burner is installed in the burnout chamber to ensure that the specified minimum combustion temperature may be maintained even in the event of a process or when burning fuels with a low N.C.V.

3.3. The WULFF inclined feed grate system

The WULFF grate system, the key element of the plant, is the current embodiment of a unique method of firing system that has been in use for several decades with excellent results. The main advantage of this grate system lies in the continuous cooling of the grate bars by means of simultaneously feed of combustion air and of recirculation of flue gas, that are, for the most part, independent of the oxygen requirements of the combustion process. The supply of cooling air and recirculated flue gas is controlled in accord with both the required cooling in each grate zone and the requirements for optimum combustion control. Due to the minimization of the local partial pressure of oxygen and of the flame temperature, the NO_x emission of the WULFF grate is very low compared to other commercial firing systems of a

similar nature. Other advantages and special features of this firing system are described in the following paragraphs.

3.4. Noncombustibles

Studies of the clinkering properties of the fuel have shown that clinker begins to liquefy in the temperature range 900 - 1100 °C (1650 - 2000 °F). This temperature range is below the regulatory requirement for a minimum combustion temperature of 1200 °C (2200 °F).

A further difficulty is that the presence in the fuel of aluminum and/or glass, originating principally from window frames in the feed, cannot be ruled out. Both substances begin to melt at temperatures as low as 600 °C (1100 °F). Molten glass or aluminum can lead to erosion or blockage of the grate bars.

A typical property of slag from wood-burning is its relatively low viscosity. The slag can be described as more "free-flowing" than "glutinous". So it was feared that a combustion temperature in excess of 1200 °C would automatically lead to the production of liquid slag, which coats and damages the fireproof brickwork. A further problem is that particles of fuel may be carried out of the furnace by the flue gas thereafter settling on the inside wall of the cylindrically-shaped burnout chamber as liquid clinker. It was clear from this that very high combustion temperatures would inevitably lead to formation of slag, if only for short periods.

Steps have been taken to mitigate this difficulty by designing and manufacturing the grate bars of the WULFF inclined feed grate and the drive system for the movable grate bars in such a way as to prevent, or at least greatly reduce, damage due to slag formation.

A notable feature of the WULFF grate bars is the high strength of the material of construction and high resistance to abrasion. The special cast steel used for the grate bars has high chromium and nickel contents, is heat-resistant up to 950 °C (1750 °F), and has a high surface hardness due to an increased silicon content.

The basic principle of the WULFF grate system is the feed motion of every other row of grate bars; the rows in between are fixed. The design of the grate bars and the kinematics of the drive system are tuned to each other to enable a feed-flow motion over the full length of the non-moving grate bars; by this means the top surface of the non-moving grate bars is fully

"cleared". The design places special importance on the parallelism of the moving grate bars in relation to the fixed bars, so as to cause the front edge of the grate bars to totally scrape the plane of the fixed bars.

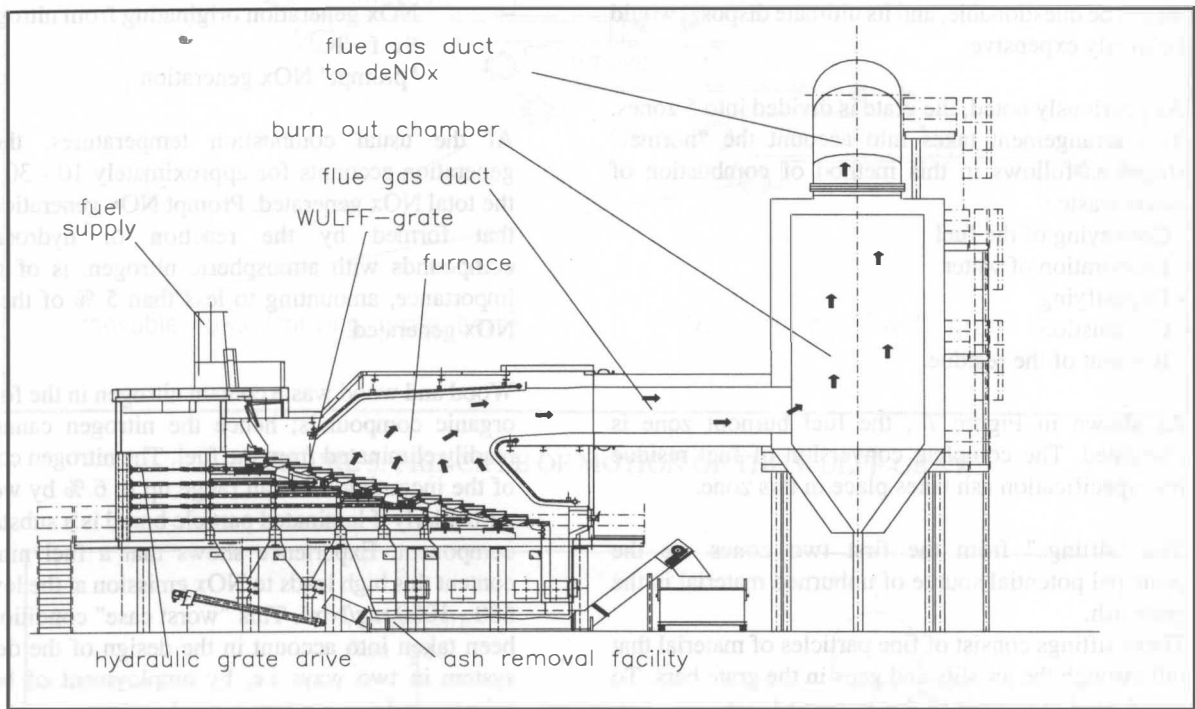


FIGURE 4: VIEW OF FURNACE AND GAS BURN OUT CHAMBER

The length of the mechanical feed-flow motion as well as the speed are individually adjustable for each of the 5 grate zones.

The principle of motion of the WULFF grate system is illustrated in Figure 5 .

However, for reasons having to do with slagging the plant should not be operated with a combustion temperature as high as 1200 °C (2200 °F), but at the lower temperature of approximately 950 °C (1750 °F). Application was therefore made to the licensing authority to allow operation at a lower temperature no less than 950 °C, in accordance with the exception permitted by the German environmental standard. This was granted, subject to proof, that the emissions, especially of polycyclic aromatic hydrocarbons (PAHs), dioxins, furans and polychlorinated biphenyls (PCBs), are no greater at 950 °C than at 1200 °C. This proof had to be provided, if technically feasible, by means of operational tests at both 1200 °C and 950 °C.

Accordingly, the flue gas recirculation system had to be designed so as to enable the plant to be operated at both temperature levels.

The basic design arrangement of the flue gas recirculation system serving the secondary combustion zone is shown in Figure 6 . When operating at 1200 °C, damper No.1 is used to maintain temperature at 1200 °C. Damper No.2 is used to maintain a temperature of approximately 950 °C, the temperature required for the SNCR systems, downstream of the burnout chamber.

When operating at 950 °C, the required minimum temperature in the burnout chamber is maintained by means of damper No.1, and damper No.2 is closed.

3.5. Unburned carbon in the ash

Performance specifications require that the carbon content of the grate ash and of the fly ash exiting the burnout chamber should be limited to max. 1 % by weight; otherwise suitability of landfilling of ash would be questionable, and its ultimate disposal would be overly expensive.

As previously noted, the grate is divided into 5 zones. This arrangement takes into account the "normal" stages as follows in this method of combustion of wood waste :

- Conveying of the fuel
- Evaporation of water
- Degasifying
- Combustion
- Burnout of the residue.

As shown in Figure 7 , the fuel burnout zone is elongated. The complete conversion of fuel residue into specification ash takes place in this zone.

The "siftings" from the first two zones are the principal potential source of unburned material in the grate ash.

These siftings consist of fine particles of material that fall through the air slits and gaps in the grate bars. To avoid need to dispose of this unburned material, as is, the siftings from the first two grate zones are re-fed into the furnace by blowing them into the combustion zone.

3.6. Nitrogen content of the fuel

Nitrogen oxides are generated in furnaces in three principal ways:

- thermal NOx generation
- NOx generation originating from nitrogen in the fuel
- "prompt" NOx generation.

At the usual combustion temperatures, thermal generation accounts for approximately 10 - 30 % of the total NOx generated. Prompt NOx generation, i.e. that formed by the reaction of hydrocarbon compounds with atmospheric nitrogen, is of minor importance, amounting to less than 5 % of the total NOx generated.

Wood and wood waste contain nitrogen in the form of organic compounds; hence the nitrogen cannot be readily eliminated from the fuel. The nitrogen content of the incoming fuel can range up to 6 % by weight, particularly if laminated particle board is a substantial component. Experience shows that a fuel nitrogen content this high leads to NOx emission at the level of 600 - 1000 mg/Nm³. This "worst case" condition has been taken into account in the design of the deNOx system in two ways i.e. by employment of both a primary and a secondary control system :

As a primary control measure, the combustion air and recirculated flue gas are each supplied to the furnace in multiple stages. This enables the local combustion temperature as well as the local oxygen level to be adjusted and controlled to prescribed limits. Experience has shown that deNOx efficiencies of 50 - 70 % can be achieved in this manner.

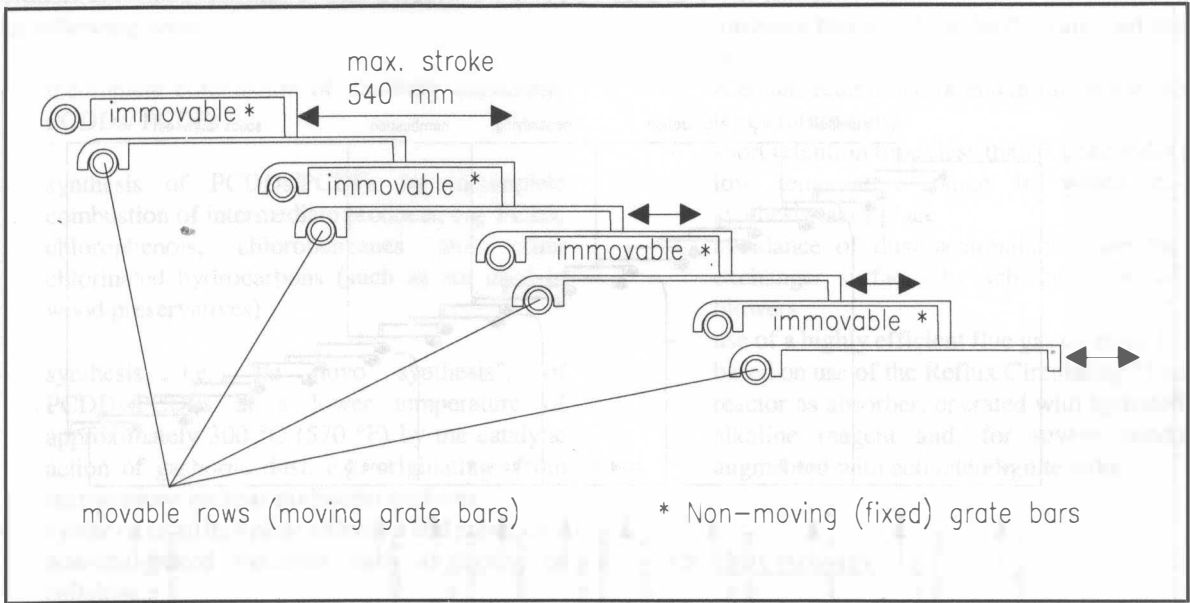


FIGURE 5: PRINCIPLE OF MOTION OF THE WULFF-GRATE

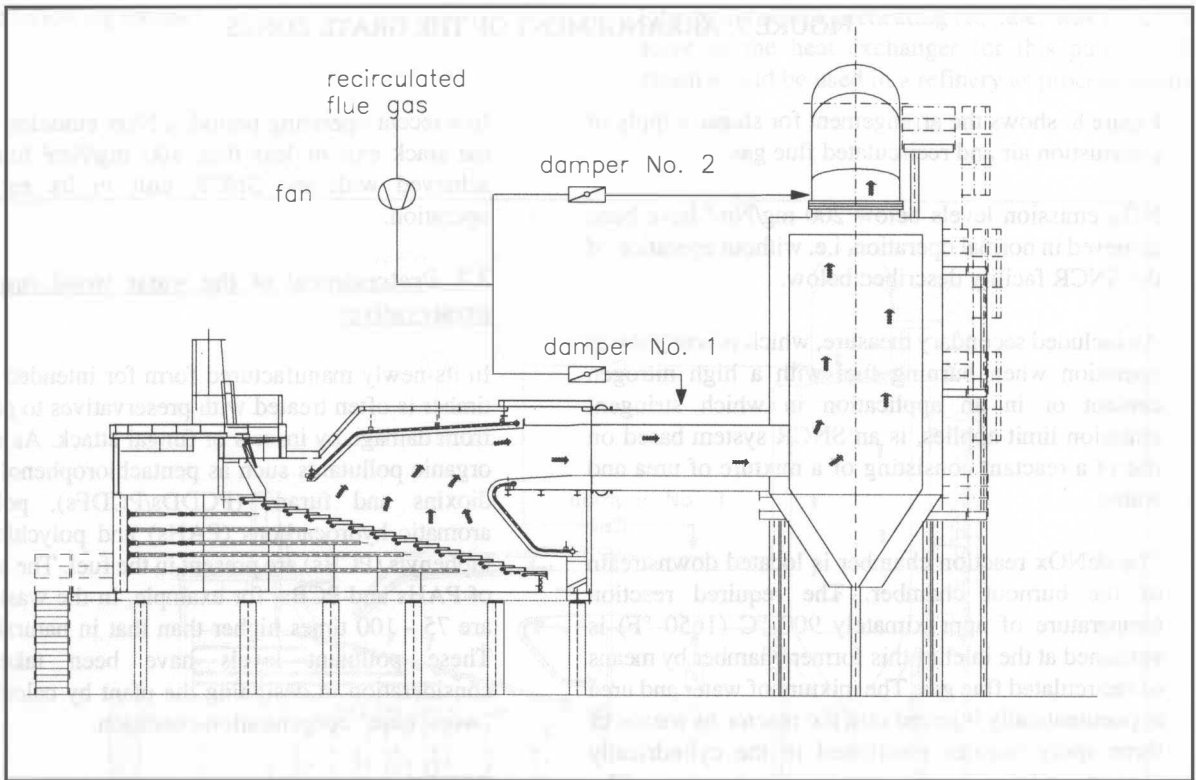


FIGURE 6: ARRANGEMENT OF THE FLUE GAS RECIRCULATION SYSTEM SERVING THE SECONDARY COMBUSTION ZONE (GAS BURN OUT CHAMBER)

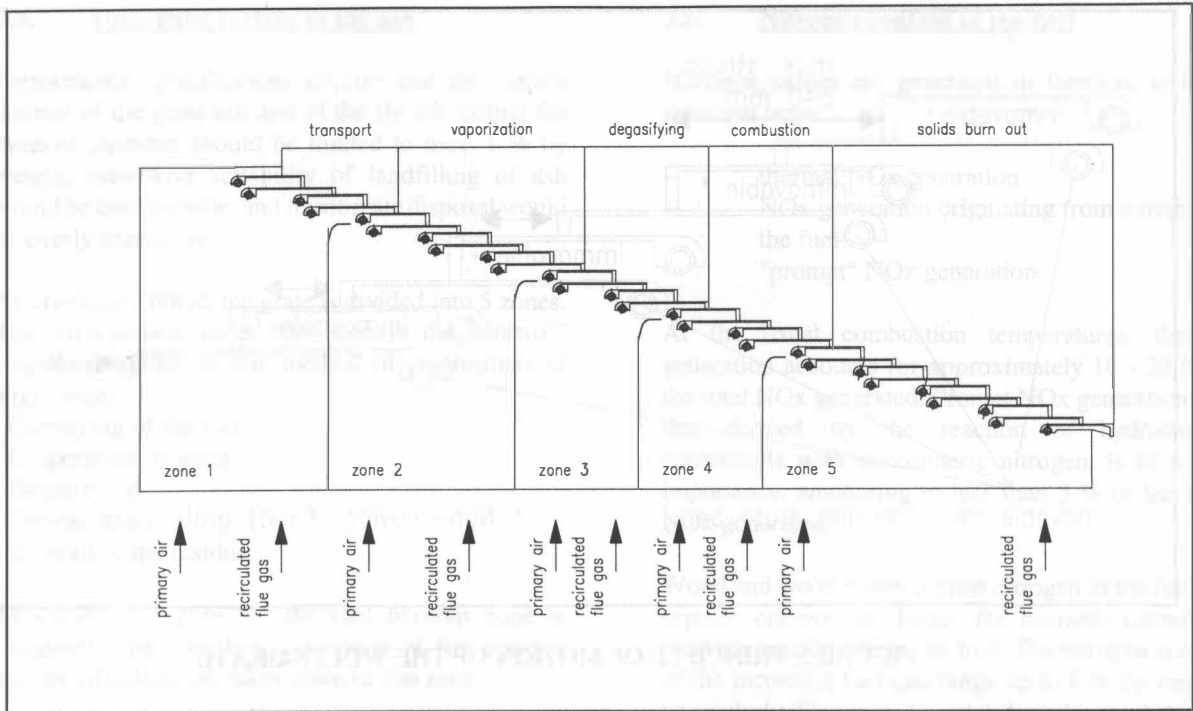


FIGURE 7: ARRANGEMENT OF THE GRATE ZONES

Figure 8 shows the arrangement for staged supply of combustion air and recirculated flue gas.

NO_x emission levels below 200 mg/Nm³ have been achieved in normal operation, i.e. without operation of the SNCR facility described below.

An included secondary measure, which is brought into operation when burning fuel with a high nitrogen content or in an application in which stringent emission limit applies, is an SNCR system based on use of a reactant consisting of a mixture of urea and water.

The deNO_x reaction chamber is located downstream of the burnout chamber. The required reaction temperature of approximately 900 °C (1650 °F) is sustained at the inlet of this former chamber by means of recirculated flue gas. The mixture of water and urea is pneumatically injected into the reactor by means of three spray nozzles positioned in the cylindrically shaped inlet of the reaction chamber. The concentration of urea in the combined mixture is continuously controlled in accord with the actual measured NO_x value. Removal efficiencies of 50 - 70 % can again be achieved.

Figure 9 illustrates the basic principle of the SNCR system.

In a recent operating period, a NO_x emission level at the stack exit of less than 100 mg/Nm³ has been achieved with the SNCR unit in its early trial operation.

3.7. Pretreatment of the waste wood containing preservatives

In its newly manufactured form for intended use the timber is often treated with preservatives to protect it from damage by insects or fungal attack. As a result, organic pollutants such as pentachlorophenol (PCP), dioxins and furans (PCDDs/PCDFs), polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) are present in the fuel. The amounts of PAHs and PCBs, for example, in the waste wood are 75 - 100 times higher than that in natural wood. These pollutant levels have been taken into consideration in designing the plant by calculating a "worst case" concentration condition.

PCDDs (polychlorinated dibenzodioxins) and PCDFs (polychlorinated dibenzofurans), particularly the isomer 2,3,7,8-TCDD, better known as the "Seveso poison", are of special concern.

Broadly, dioxins and furans are liberated/generated in the following ways:

- incomplete combustion of materials containing PCDDs/ PCDFs
- synthesis of PCDDs/PCDFs by incomplete combustion of intermediate products, e.g. PCBs, chlorophenols, chlorobenzenes and other chlorinated hydrocarbons (such as are used in wood preservatives)
- synthesis, i.e. "de novo synthesis", of PCDDs/PCDFs at a lower temperature of approximately 300 °C (570 °F) by the catalytic action of gasborne dust, e.g. originating from incrustations on heat exchanger surfaces
- synthesis from inorganic chlorides and previously non-chlorinated materials such as lignite or cellulose.

These mechanisms, particularly the de-novo synthesis that takes place at relatively low temperatures, have been taken into account in the design of the plant by the following means :

- intensive mixing of combustion air, fuel and flue gas
- adequate retention time and turbulence in the high temperature range
- short retention time (less than 0.1 seconds) in the low temperature range in which de-novo synthesis takes place
- avoidance of dust accumulations on the heat exchanger surfaces by scheduled use of soot blowers
- use of a highly efficient flue gas cleaning process based on use of the Reflux Circulating Fluid Bed reactor as absorber, operated with hydrated lime alkaline reagent and, for severe conditions, augmented with activated lignite coke.

3.8. Heat recovery

The original design of the plant envisioned that the calorific value of the wood waste would be converted into superheated steam at 11 bar (174 psig) and 250 °C (482 °F) with a boiler efficiency of > 85 %. A fire-tube boiler with a preheating chamber was selected to serve as the heat exchanger for this purpose. The steam would be used in a refinery as process steam.

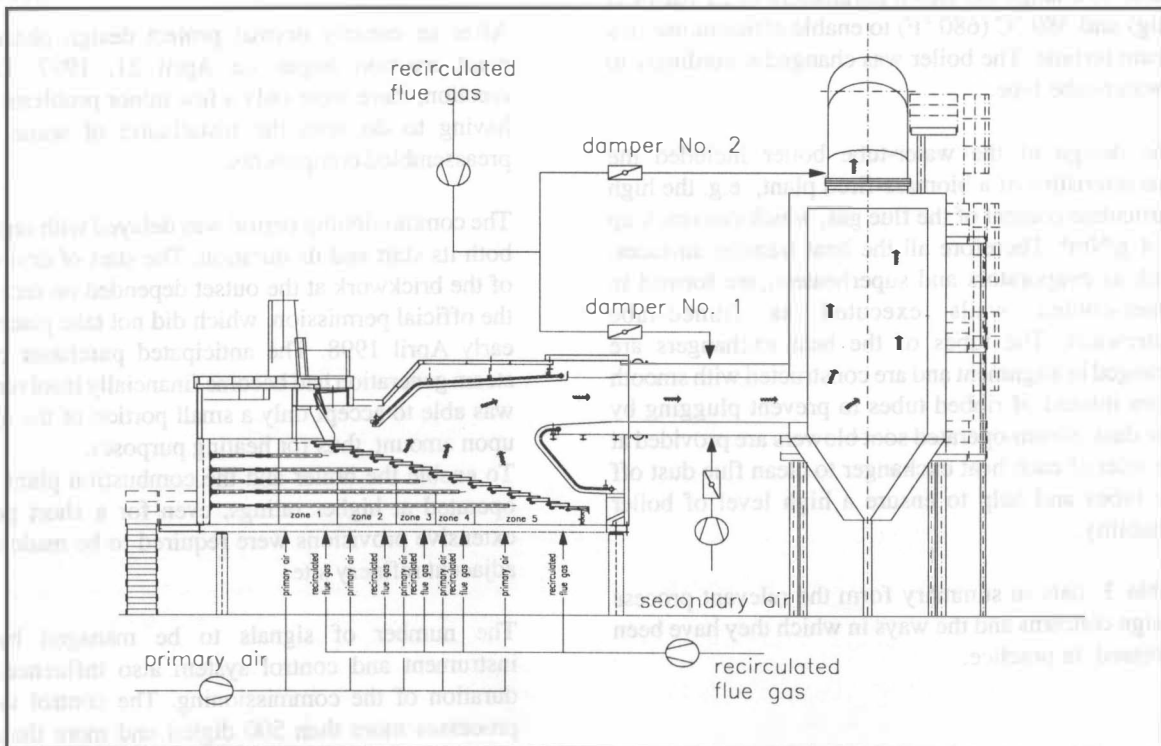


FIGURE 8: DISTRIBUTION OF COMBUSTION AIR AND FLUE GAS RECIRCULATION

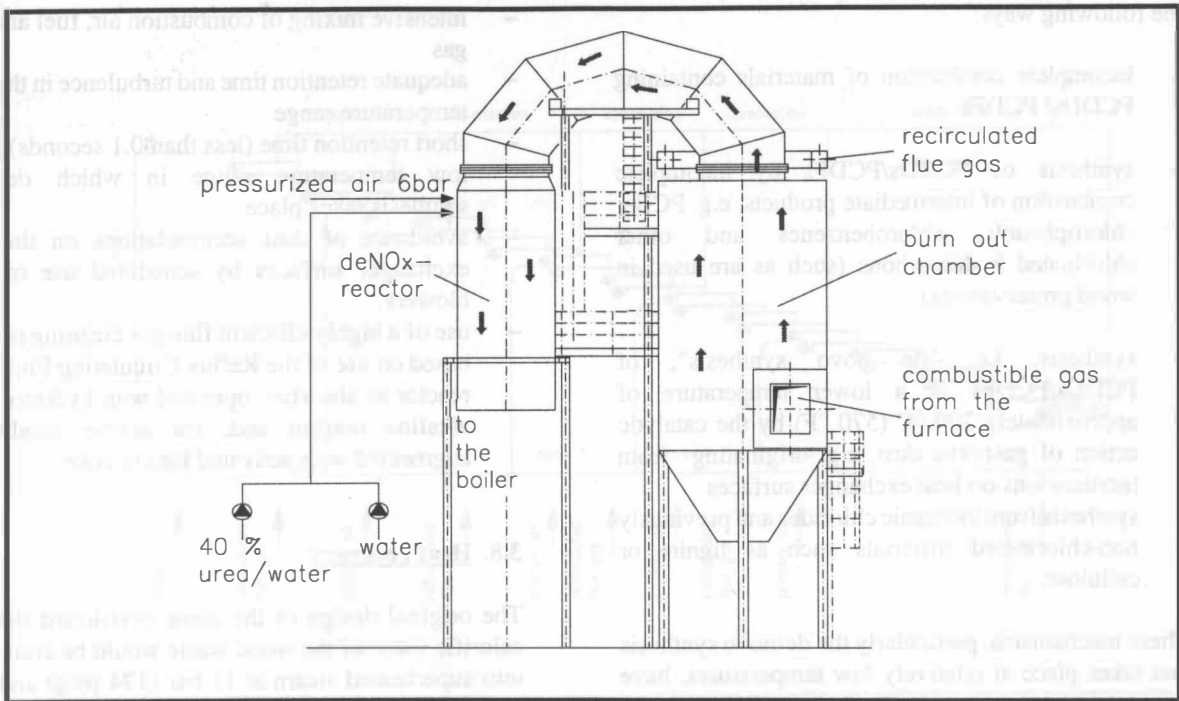


FIGURE 9: ARRANGEMENT OF THE SNCR SYSTEM

At an early stage of the project, refinery's interest in purchase of the steam came into question. The client chose to change the steam parameters to 29 bar (435 psig) and 380 °C (680 °F) to enable efficient use in a steam turbine. The boiler was changed accordingly to a water-tube type.

The design of the water-tube boiler included the characteristics of a biomass-fired plant, e.g. the high particulate content of the flue gas, which can reach up to 4 g/Nm³. Therefore all the heat transfer surfaces, such as evaporators and superheaters, are formed in water-cooled walls executed as finned-tube waterwalls. The tubes of the heat exchangers are arranged in alignment and are constructed with smooth tubes instead of ribbed tubes to prevent plugging by flue dust. Steam-operated soot blowers are provided at the inlet of each heat exchanger to clean flue dust off the tubes and help to ensure a high level of boiler reliability.

Table 3 lists in summary form the relevant process design concerns and the ways in which they have been addressed in practice.

4. EXPERIENCE DURING PROJECT DESIGN, ERECTION AND COMMISSIONING

After an entirely normal project design phase, the plant erection began on April 21, 1997. During erection, there were only a few minor problems these having to do with the installation of some large, preassembled components.

The commissioning period was delayed with regard to both its start and its duration. The start of drying-out of the brickwork at the outset depended on receipt of the official permission, which did not take place until early April 1998. The anticipated purchaser of the steam generation had become financially insolvent and was able to accept only a small portion of the agreed upon amount, thus for heating purposes.

To enable the boiler and the combustion plant to be operated at higher ratings, even for a short period, extensive provisions were required to be made at the adjacent refinery site.

The number of signals to be managed by the instrument and control system also influenced the duration of the commissioning. The control system processes more than 500 digital and more than 120 analog input signals, creating 180 digital and 30 analog outputs. The control system is based on 2

process stations with separate CPUs, served by 3 high-power PCs.

The fuel preparation plant (not supplied by WULFF) has been more susceptible to upsets than expected. (The operation of the preparation plant directly influences the operation of the combustion and boiler plant.)

An area particularly prone to upsets was separation of the fines, which if the air classifier breaks down, are no longer wafered but instead pass directly into the day-bin and thus become part of the fuel entering the furnace.

A further problem was that these fines were gathered in the first two grate zones as "siftings" and pneumatically re-fed into the furnace. More than 50 % of this material consisted of noncombustibles that melted immediately and coated the inside of the furnace and the burnout chamber with slag. This was the reason for the sole major modification to the WULFF plant during the commissioning, i.e. collection of the fines in separate bins instead of re-feeding them into the furnace.

Beyond this it was necessary to carry out only minor adaptations and repairs during the commissioning.

The plant was handed over to the client on July 15, 1998.

5. EXPERIENCE DURING COMMERCIAL OPERATION

During the first few months of commercial operation, it was possible to operate the plant at a rating of only approximately 50 % due to the lack of use for the steam. Even in this operating mode, there were only a few minor problems, such as breakdown of a valve actuator and failure of a damper, problems partly caused by the operators' lack of process-system experience.

Only during the initial official emission test runs were there problems while the plant was being operated with combustion temperature in excess of 1200 °C and at 100 % rating. Dust particles from the fuel melted inside the burnout chamber, flowed down the walls and filled the ash hopper with liquid slag. The inside of the chamber was entirely coated with a 1 - 2 cm layer of adherent slag. As a result, the plant had to be taken out of operation immediately after the test operations conducted during 10 hours at 100 % rating and allowed to cool down, after which the solidified slag was removed. The quantity of slag arising from the 10 hours of operation was about 600 kg, representing 3 % of the weight of the fuel charged.

TABLE 3 : SYSTEM DESIGN MEANS TO OVERCOME GENERIC PROBLEMS

Highlight	Problem / requirement	Effect	Process / design
combustion conditions	2 sec. retention time above 1200 °C (2200 °F)	generation of carbon monoxide and diverse hydrocarbons	voluminous design of the gas burn-out area, completely cladded with brickwork, supplemental oil burner
non-combustibles	clinkering	plugging the furnace, damaging of the brickwork, reliability of the plant	- clinker-resistant design of the grate bars and of the grate - the flue gas recirculation is designed to afford operation of the plant at reduced temperature (950 °C, 1750 °F)
unburned carbon	request of the buyer to limit the carbon-content in the grate-ash to 1 %	high dumping fee	extended solids burn out area on the grate
nitrogen-content of the fuel	possible nitrogen content up to 6 % ; increased NOx-generation	up to 1000 mg/m ³ Nox in the flue gas possible without any measures	primary : stepped combustion air supply with controlled flue gas recirculation secondary: SNCR based on urea
pretreatment with preservatives	formation of dioxins/furans by incomplete combustion, synthesis of pre-compounds or by catalytic influence of dust	1 - 10 ng/m ³ in the flue gas	- high destruction efficiency at high temperature with adequate retention time - short retention time at reduced temperatures to prevent "de-novo-synthesis" - avoidance of dust accumulation - feed of activated lignite coke to the flue gas cleaning system
heat generation	economical and ecologically- beneficial use of the net calorific value	N.C.V. 12 - 20 MJ/kg furnace rating max. 8,35 MW	generation of superheated steam either to drive a steam turbine or for refinery supply
contamination by sulphur, chlorine and flourine	sulphur oxide chlorine compounds fluorine compounds	200 - 600 mg/m ³ in the flue gas 30 - 100 mg/m ³ in the flue gas 20 - 50 mg/m ³ in the flue gas	semi-dry flue gas-cleaning process based on a RCFB as absorber and conditioning of the flue gas by humidification
contamination by mercury	mercury and compounds of mercury	10 - 50 mg/m ³ in the flue gas mainly as HgCl ₂	semi-dry flue gas-cleaning system using hydrated lime and activated lignite coke reagents
contamination by dust and heavy metals	fly ash antimonium & cadmium other heavy metals	5000 - 10000 mg/m ³ in the flue gas 100 - 600 mg/m ³ in the flue gas 0,2 - 1 mg/m ³ in the flue gas	use of a baghouse as particulate removal

Clinker formation occurred during the commissioning as well; however, this clinker was produced on the grate and was automatically discharged into the wet ash extractor by the grate action.

The work to remove the slag from the ash hopper caused the plant to be out of service for a total of six days, including the time required for cooling down and subsequent heating up.

To continue the operation of the furnace at a combustion temperature of 1200 °C and 100 % capacity would not only have led to serious reduction of the availability of the plant. It also would have damaged the brickwork and might have made it necessary to completely replace the inner layer. The licensing authority thereupon immediately gave temporary permission for the plant to be operated at a minimum temperature of 950 °C, but on the condition that if technically feasible, the results of the emission tests at 950 °C would show the emission levels to be no higher than at 1200 °C.

Due to the above-mentioned plant problems caused by the fast melting of ash at temperatures above 1200 °C this plant operation and concurrent the emission tests could not be continued. Therefore the required emissions measuring time was not fully available. The test results (one run) obtained under these conditions were not entirely representative, but showed no great differences from the results at 950 °C. These results are shown in Table 4 .

Results of both official test runs meet and are even far below the emission limits of the German environmental standard (17. BImSchV).

6. RESULTS OF THE PROJECT

The obvious conclusion to be drawn from this project is that our intention to build Germany's first working plant for combustion of wood in compliance with the legal requirements has been fully achieved.

For subsequent projects, the furnace design aimed at a separate burnout chamber will not be used, if the necessary overall height is available. Lacking this, the project detailed herein required that the gas burnout function is designed to be fulfilled by the separate structural component described.

Figure 10 shows a design for a combustion plant for wood waste in which the burnout chamber is incorporated within the first pass of a water-tube boiler.

Moreover, studies and calculations show that this design featuring a water-tube boiler with a first pass located vertically above the grate (water-cooled waterwalls, partly lined with castable refractory) and using a following empty pass (as the reaction section for NO_x control) is preferable to the initially used, commercial design detailed herein and it can also be erected in considerably less time.

TABLE 4: RESULTS OF OFFICIAL EMISSION TEST RUNS

Component	Units	30min emission limit as per 17. BImSchV	Test run "A"	Test run "B"
carbon monoxide ¹⁾	mg/Nm ³	100	1	12
total dust content	mg/Nm ³	30	3	3
total carbon	mg/Nm ³	20	0.3	0.3
hydrogen chloride	mg/Nm ³	60	0	0
hydrogen fluoride	mg/Nm ³	4	0.1	0.1
sulphur dioxide	mg/Nm ³	200	57	2
nitrogen oxides	mg/Nm ³	400	239	67
cadmium & thallium	mg/Nm ³	0.05	0	0
mercury & its compounds	mg/Nm ³	0.05	0.013	0.008
other heavy metals ²⁾	mg/Nm ³	0.5	0.094	0.140
dioxins & furans	ng/Nm ³	0.1	0.0085	0.0074

1) measured as a 1-hour average

2) sum of antimony, arsenic, lead, tin, chrome, copper, cobalt, manganese, nickel and vanadium

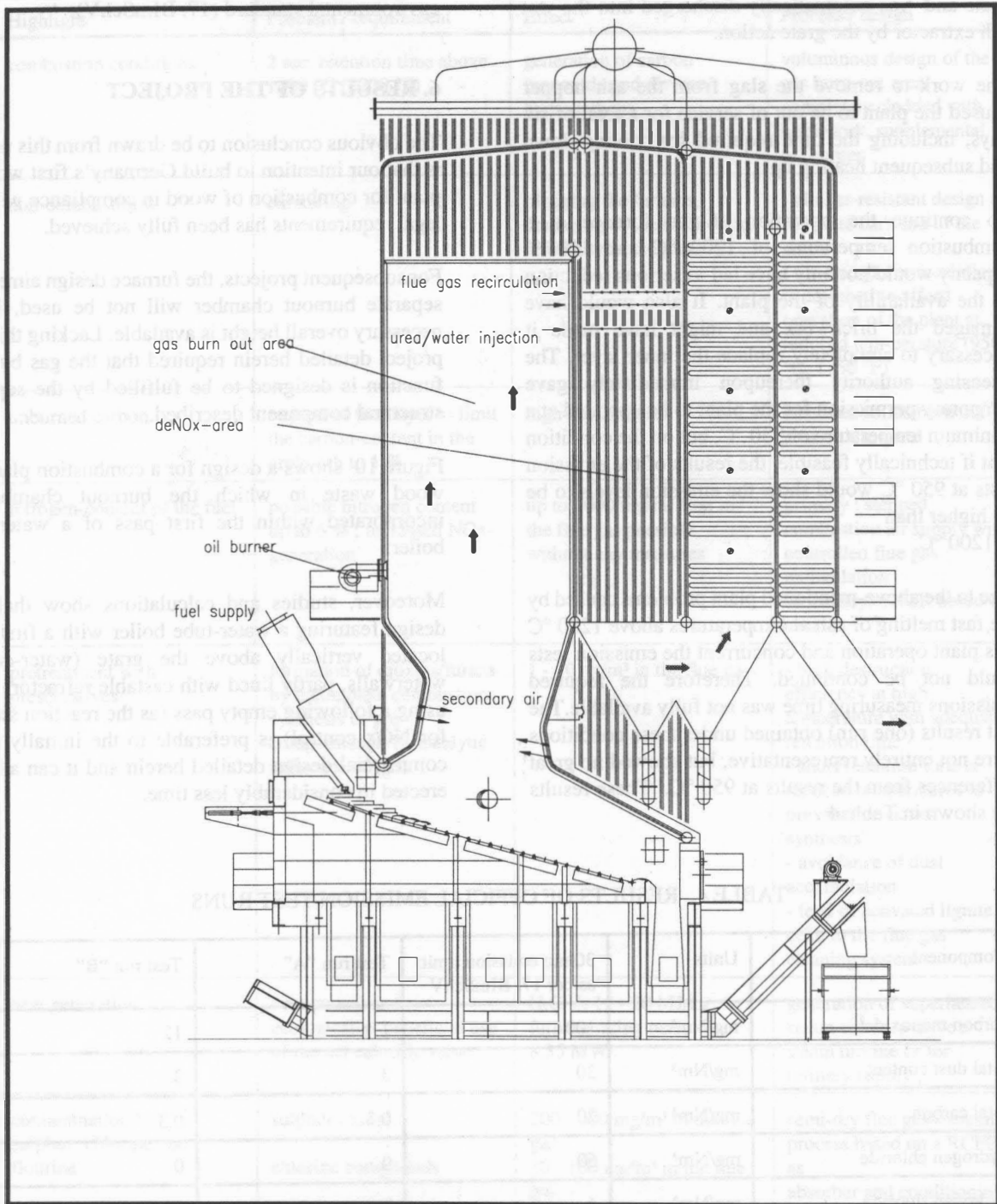


FIGURE 10: DESIGN FOR FUTURE INSTALLATIONS OF THE WULFF-GRATE INTEGRATED WITH A WATER TUBE BOILER FOR WASTE BIOMASS COMBUSTION