Using Infrared Cameras, Fuzzy Logic and Acoustic Temperature Measurement to Improve Combustion in MWCs

Peter Daimer, Walter Schäfers and Hans-Ulrich Hartenstein
L. & C. Steinmüller GmbH
Fabrikstrasse 1
D-51643 Gummersbach, Germany

Anthony Licata
Licata Energy & Environmental Consultants, Inc.
2150 Central Park Avenue
Yonkers, New York 10710-1843

ABSTRACT

A significant step for the improvement of firing rate and combustion control is the use of infrared thermography. Such a system has been successfully applied by L. & C Steinmüller GmbH (Steinmüller) a long period of time at the Stapelfeld municipal waste combustor (MWC) located in Germany.

A camera installed on the boiler top casing supplies instantaneous information on the combustion conditions on the grate. In the event of undesired changes in firing position or firing length, countermeasures may be instituted immediately. A control system based on fuzzy logic, divided into several stage each of which includes a short-term and a long-term strategy, has been developed for this purpose. This system reduces fluctuations during combustion to an unavoidable minimum.

The acoustic temperature measurement system installed in the first pass of the boiler provides valuable information about the temperature distribution in the zone. This allows the control room operator to adjust the distribution of secondary air to the front and rear row of nozzles so that uniform temperature and flow distribution are maintained at all times.

Both installations allow the firing system to operate at more optimized conditions which results in such positive effects as reduced emissions and increased steam production.

INTRODUCTION

Today there is no doubt that waste should be avoided wherever possible and that recycling should be established wherever feasible. Despite these measures, there are still considerable quantities of waste that have greatly varying combustion properties and, in some cases, high loads of pollutants.

Since the Municipal Waste Guidelines in Germany and comparable regulations in other countries such as in the USA, impose strict requirements for the disposal of waste with regard to unburned residues in the ash, great demands are placed on the combustion technology. In order to be able to meet possibly even more stringent local requirements for the burnout of ash and flue gas emissions under all conditions, all components of such a plant must be carefully coordinated.

A plant designed according to these principles has now gone into operation in the northern area of the city of Cologne (Figure 1). The plant has 4 units and a total throughput capacity of 1750 tpd. The Steinmüller Company has full responsibility for the turnkey engineer, procure and construct (EPC) delivery of the facility including the erection and start-up of this modern plant. The first refuse fire was lit on schedule in mid-October 1997. Since the beginning of 1998 all four units have operated at full capacity.

CLASSIFICATION OF SPECIFIC AREAS FOR DEVELOPMENT POTENTIALS

A modern residual waste combustion plant consists of four areas. These areas are inseparably linked:

- Combustion
- Utilization of energy
- Flue gas cleaning
- Treatment and disposal of residues

The following is a discussion of the possibilities for improvement and optimization to be found in particular areas.

Combustion

Steinmüller has been building grate-firing plants for more than 70 years. At first they were used for the combustion of brown, lignite and bituminous coal and, soon after, also for other combustible substances such as wood, coffee residues, wheel grindings, peat, bark, food processing residues, waste paper, etc. During this time the structural design and process characteristics of the grate were steadily improved so that a widely tested and highly developed system is available today. The stoker itself is not covered in detail in this paper but it is described extensively elsewhere.

Infrared (IR) Thermography

Due to the heterogeneous and constantly varying composition of waste, the heating value of waste fed to the combustion chamber at any given moment is unknown. At the same time, exact metering is not possible because of the fluctuating consistency. Thus, the combustion properties of waste change within short periods of time. Adaptation of firing parameters to the variations in fuel properties is possible only to the extent to which the effects of altered burning behavior can be determined. Usually this determination is effected only by measurement of the CO and O_2 content in the flue gas, the quantity of steam, and subjective observation of the conditions of fire on the grate by operating personnel.

In contrast, more detailed and, above all, objective information concerning the actual course of combustion can be obtained by means of IR thermography. This measurement principle uses the fact that everything at temperatures above absolute zero emits electromagnetic radiation in the infrared region. This radiation, coming from a surface, is detected and converted to a temperature distribution.

In order to be able to detect the temperature distribution on the firebed of a refuse combustion facility, the camera is installed on the boiler at the top of the furnace (Figure 2). Possible disturbances on the optical path between camera and refuse surface are minimized by the selection of a suitable spectral region. The required information is selected from infrared photographs by special analytical methods. Thus, for example, it can be determined whether the location and size of the main burnout zone is in the desired region or threatens to run out of this area. In this case, variation of air distribution and/or grate or metering control (length of stroke and frequency) can correct the position of the burnout zone and supply combustion air correctly as needed. However, the procedure described is not limited to the whole grate. It is also applicable to specific grate zones individually so that thermal asymmetries are largely reduced.

In order to make optimal use of the possibilities mentioned, a control system based on fuzzy logic was developed. This system is divided into several stages -- regulation of waste throughput, regulation of fire location, optimization of the O_2 concentration -- each of which includes a short-term and a long-term strategy.

With this system, variations in the course of combustion are reduced to an unavoidable minimum. Thus, the fire can be maintained constantly at optimum conditions and the following positive effects are produced:

- Improvement in the burnout quality of the ash,
- Improvement in gas burnout due to optimized mixing in the region of secondary air injection,
- Air distribution adapted to requirements and optimized locally and with time, which can be used, for example, for the reduction of excess air (greater efficiency and less flue gas cleaning),
- Smaller variations in steam flow and hence higher overall steam quantities,
- Narrower switch-on tolerances for back-up burners and less back-up burner operation.

Acoustic Temperature Measurement

Another way to obtain additional information is to use acoustic temperature measurement. This measuring method is based on the physical relationship that absolute temperature is proportional to the square of sonic speed. In the minimal design, such a system consists of two facing units (Figure 3). Each unit can be connected as a transmitter as well as a receiver. For temperature measurement, an audible noise signal is pneumatically generated in the frequency range between 200 Hz and 3000 Hz. The time duration is determined from the transmission to the detection of the signal by means of special correlation techniques. Then, through this, the average temperature present in the measuring path is calculated.

By using four transmitting and receiving units, as shown in Figure 4, flue gas temperatures in the region of the front and back walls can be determined. Great differences between these temperatures indicate flow gradients which promotes corrosion on one hand and, on the other, may lead to interference with dwell-time conditions. With information concerning temperature conditions, it is possible to adjust the secondary air distribution to the front and rear nozzle rows so that uniform temperature and flow distribution are maintained at all times.

The use of a larger number of transmitting/receiving units (six and more units) is of interest when the SNCR process, i.e., the injection of ammonia at high temperatures, is used for the removal of NO_x from the flue gas. Here it is of crucial importance to keep the reducing agent injected into the flue gas stream within the temperature window of 850°C to 950°C in the existing two to three injection levels.

Since the acoustic signal of each transmitter can be picked up by all other units, 15 evaluable independent time durations can be obtained with the use of, for example, eight transmitting/receiving units. With this time information, the isothermal field in the measuring level can be calculated by means of a computer. In addition, area-weighted average temperatures and other data can also be determined from it. In this way it is possible to adjust local ammonia injection very accurately to the actual flue gas temperatures.

Such a system has been successfully used in the waste-to-energy (WTE) plant MVB Hamburg for several years. The accuracy and reproducibility of the process are very good. Therefore, acoustic temperature measurement is also used for monitoring of combustion chamber conditions with the approval of the authorities.

In-Situ Laser Measurement

In addition to temperatures and temperature fields, process-oriented analytical values for O_2 and H_2O, among other gases, are also important for optimal combustion control. The methods hitherto customarily used for the measurement of for example O_2 concentration at the boiler outlet must either be protected by suitable measures against the dust contained in the flue gas or have a greater inertia. These basic disadvantages do not occur in in-situ laser measurement which works without contact.

This measuring principle uses the molecular structure of the gases by which certain spectral regions exist in which electromagnetic radiation (e.g., visible light or infrared radiation) is absorbed. There each gaseous component has very specific spectral ranges.

These are just the properties used by NIR (near infrared) spectroscopy, in which a laser beam whose wavelength corresponds exactly to a spectral line of the gas to be examined is produced by means of a diode laser. If this laser beam traverses a gaseous mixture, it is reduced in strength exclusively, aside from solid particles by this gaseous constituent. The degree of weakening is a measure of the number of molecules within the measuring path from which the concentration of the gaseous constituent sought is directly determined. A reference measurement outside this spectral line allows to determine the beam weakening due to solid particles (dust, ash) found in the gas stream and taken into consideration. Therefore, unlike more broad-band methods, NIR spectroscopy can be used even at high dust loads and is, therefore, especially suitable for concentration measurements in the raw gas of waste combustion plants.

In the NIR spectrometers used, the process computers in each instance form a unit with the corresponding laser sources. In these basic instruments, the laser beam is sent into a fiber-optic cable and routed to the corresponding measuring point. There it is transmitted by a transmitter through the gas stream to be examined to a facing detector. From this receiver, the signal is in turn carried on the optical path to the basic instrument where these signals are correspondingly evaluated and the gas concentration calculated.

In summary, measurement of concentration by means of NIR spectroscopy has the following advantages:

- Contactless and, therefore, wear-free.
- Short response times and therefore process-oriented.
- Determination of average value over the measuring path, thereby considerably minimizing the risk of unrepresentative measurements in gas streams.

In addition to O_2 concentration measurement, it is also advisable to determine the water content at the boiler outlet. This provides information concerning refuse quality which can be included in regulating the process.

Flue Gas Cleaning

In the late 70's, Steinmüller received orders for the first flue gas cleaning plants serving special waste incinerators. Later, large flue gas desulfurization and $DeNO_x$-removing plants were built for power plants. In that way, Steinmüller steadily participated in the rapid development of these techniques.

However, since the reduction of NO_x in the flue gases in systems used today already takes place in the combustion chamber by the SNCR method, we shall go into this further here.

Reduction of NH_3 Slip by SNCR with Catalytic Oxidation

This flue gas cleaning method is illustrated schematically in Figure 5. The essential part of the method is the injection of ammonia or UREA into the combustion chamber at temperatures between 850°C and 950°C. In this thermal process, nitrogen oxides are selectively reduced to elemental nitrogen. In order to obtain high conversion of nitrogen oxides, ammonia must be metered proportions greater than stoichiometric.

Some of the ammonia supplied in greater than stoichiometric proportions is converted into nitrogen and water while the rest remains unreacted as so-called "slip" in the exiting flue gas. The level of ammonia slip appearing depends upon the desired degree of reduction, upon the effectiveness of mixing, and upon how accurately the optimum temperature window for NO_x removal can be controlled under the constantly varying load conditions of refuse combustion.

The SNCR technology is a simple and low-cost method for the removal of NO_x from flue gas. Only the ammonia slip is disturbing since at low temperatures it settles on filter dusts and causes some odor problems upon contact of these dusts with water. This may lead to considerable problems in disposal of the residues.

Catalytic oxidation of ammonia within flue gas oxygen has been proven to be a very effective countermeasure. There the undesired ammonia is converted into the harmless substances nitrogen and water according to the equation $4\ NH_3 + 3\ O_2$ ® $2\ N_2 + 6\ H_2O$.

Lost catalyst iron-II-sulfate, an inexpensive and readily available residue of the titanium dioxide production, is injected into the flue gas at about 700°C, i.e., before the convective heating surfaces. Even relatively small quantities can effectively limit ammonia slip. After optimization of the process, it may be expected that, despite this additional process stage, overall costs are reduced by savings in the consumption of ammonia.

Residue Treatment

Reduction and improvement in the quality of residues in waste combustion are of central importance today. For one thing, disposal costs can be reduced and, for another, the acceptance of thermal treatment processes is also increased when a major portion of residues can be utilized without reservation.

In principle, Steinmüller's technologies for residue treatment can provide any desired residue quality. They permit all statutory regulations, however strict, to be met. For example, washing processes are available for removing the soluble constituents from the ash. Completely inert residues can be obtained only by means of thermal processes. Two of the process alternatives are described below.

Ash Washing

The chloride and sulfate content in the leachate of ash from MWC's can be distinctly reduced by the use of an integrated ash wash. The water bath, present in any case in the ram ash extractor, is used for this.

In order to illustrate the mode of operation better, the conventional ash remover represented in the upper part of Figure 6 will be explained first. In this, the water level is kept constant by a float control valve, i.e., only as much water is fed in as is evaporated by the hot ash and discharged with the cold ash. The water-soluble constituents of the ash are concentrated in the water bath but are carried out with the moist ash. The ash-removal water represents a virtually saturated salt solution.

In order to achieve the leaching and separation of the water-soluble constituents, the water in the ash discharger must be continuously renewed. In doing this, the higher the throughput of water the better the ash quality becomes. As can be seen from the simplified illustration in Figure 6, the basic principle consists in that operating water is supplied to the ram ash extractor. In its passage, with the corresponding dwell time in the water box, the washing effect is obtained and the water exits through the overflow.

Because of the high percentage of suspended matter and fine particles, however, the overflow water cannot be sent directly to the waste water treatment plant of the flue gas cleaning system. An inclined-belt filter station separates the solids and transports them to a visually monitored residue container. After the container is filled, it is replaced by fork lift with an empty container. After passing through fine filtration, the salt-enriched filtrate is sent to the flue gas cleaning system as process water.

Such an ash wash has been in operation at the WTE plant MVB Hamburg for about four years. The initial difficulties were eliminated by modifications in design and process operation routine. On the basis of this experience, an improved ash wash is now coming on line in the WTE plant MVR Hamburg presently under construction.

Vitrification Processes

The EloMelt and OxiMelt vitrification processes were developed by Steinmüller as an outcome of the controversial discussion in Germany in 1992-95 concerning the disposal of residue. These processes make it possible to dispose of waste virtually residue-free.

The intermediate products bottom ash and flyash, individually or combined, are converted by electric energy in the EloMelt process and fossil energy in the OxiMelt process into the resource fractions to be recovered.

- Ferrous/non-ferrous metal
- Silicate product
- Heavy metal concentrate

The different priorities for the integration of a vitrification process in a MWC do not suggest a clear preference for the OxiMelt or EloMelt process. Each technology has specific advantages. Therefore, selection of the process must be made depending upon the specific conditions.

Energy Utilization

Waste combustion has the primary task of decomposing the organic fraction contained in the waste. Utilization of the energy contained in waste for the generation of process heat or electricity has by contrast, a lower ranking, at least in Europe. For ecological and economic reasons, however, there is an increasing effort to optimize the released energy and its use. Because this is a classic thermodynamic area, the possibilities for optimization are largely exhausted. Among other additional measures which are being discussed are the low-temperature economizer and the external superheater.

Low-Temperature Economizer

Refuse combustors are usually operated with a flue gas exit temperature at the boiler outlet of 200 to 300°C (start/end of running time). Reduction of this temperature permits better energy utilization to be achieved. But it must be recognized that the reduction of flue gas temperature is limited by the risk of dew point corrosion on the colder surfaces in the economizer region. Because of the partial pressures of SO_3 and H_2O present in usual flue gas, the feedwater temperature should not be lower than 130°C, in order to stay reliably above the acid dew point.

For the WTE plant MVR Hamburg (Figure 7), now under construction, a flue gas temperature of 170°C, constant over the running time, is provided. Because of the small temperature difference between flue gas and feedwater, a considerable increase in economizer heating surfaces is necessary as well. In order to maintain the constancy of the flue gas temperature at the same time, a drum preheater is used for preheating the feedwater.

The relatively high cost of convective heating surfaces must be balanced against the clearly improved energy utilization. Due to the reduction of the flue gas temperature from 215°C (middle of running time) to 170°C, the energy loss is reduced by about 3 percent.

Meanwhile, plants are being developed in which a further reduction of temperature at the boiler outlet to about 140-150°C is planned. There the risk of corrosion must be taken into consideration by using easily replaceable heating surfaces.

External Superheater

An improvement in thermal efficiency can also be obtained by the increase of superheated steam parameters, usually around 40 bar/400°C. With an increase in temperature, however, it should be noted that over 400°C the risk of high temperature corrosion increases exponentially.

In order to prolong the service life of superheaters thereby affected to an acceptable extent, the tube surfaces may be sheathed with high-grade good heat-conducting materials, using half shells or jacket tubes or special materials such as AC66.

Despite all these measures, the service life of heating surfaces with temperatures of 430°C and above is distinctly shorter than that with a lower superheated steam temperature. A reasonable alternative for high steam parameters is the external superheater, as is used, for example, in the Mannheim MWC Germany. Here final superheating takes place outside the flue gas stream in a separate heating surface unit using several burners.

An external superheater can also be operated very advantageously with biogas from a fermentation plant. Such gas has only traces of impurities (H_2S, NH_3) and can therefore be fired without treatment. Its heating value is in the neighborhood of 20-25 MJ/Nm^3. As an example, it may be assumed that a fermentation plant, with a throughput of 38,500 tpa supplies a burnable gas quantity of 3.8×10^6 (Nm^3)/year.

CONCLUSION

In waste combustion on the grate according to today's standard plant, areas that have a very long history of development behind them (combustion, energy utilization) are combined with areas whose development has been quite rapid in the last ten years (flue gas cleaning, ash treatment). As a result, a very high technical level overall has been reached. At the same time, the flexibility to erect a plant in accordance with the needs of the respective location is always a concern.

The process technologies presented in this paper also show that there are a number of potentials for optimization. Basically, in order to obtain the desired improvement, it is necessary that all plant areas be included in such considerations and that each component be optimally adapted to the whole plant.

REFERENCES

Lux, P.; Hartenstein, H.-U.; Licata, A. *New Developments and Applications of the Steinmüller Mass*; 6th Annual North American Waste-to-Energy Conference, Miami Beach, Florida, 1998.

Schüttenhelm, W.; Hartenstein, H.-U.; Licata, A. *An Optimized Concept for Flue Gas Cleaning Downstream of MWCs Using Sodium Tetra Sulfide for Mercury Removal*; 6th Annual North American Waste-to-Energy Conference, Miami Beach, Florida, 1998.

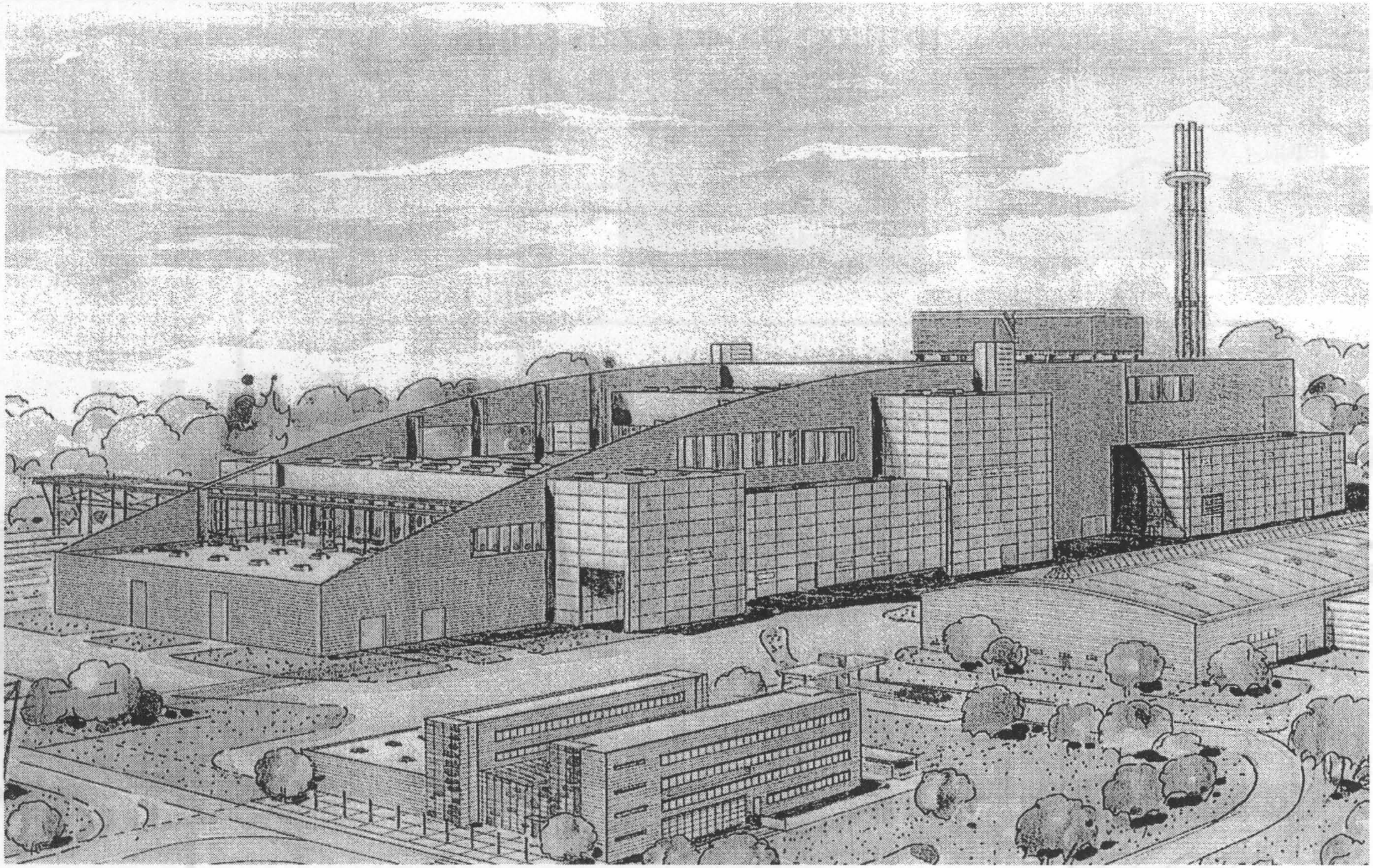


Figure 1. **Cologne Waste-to-Energy Plant**

STEINMÜLLER

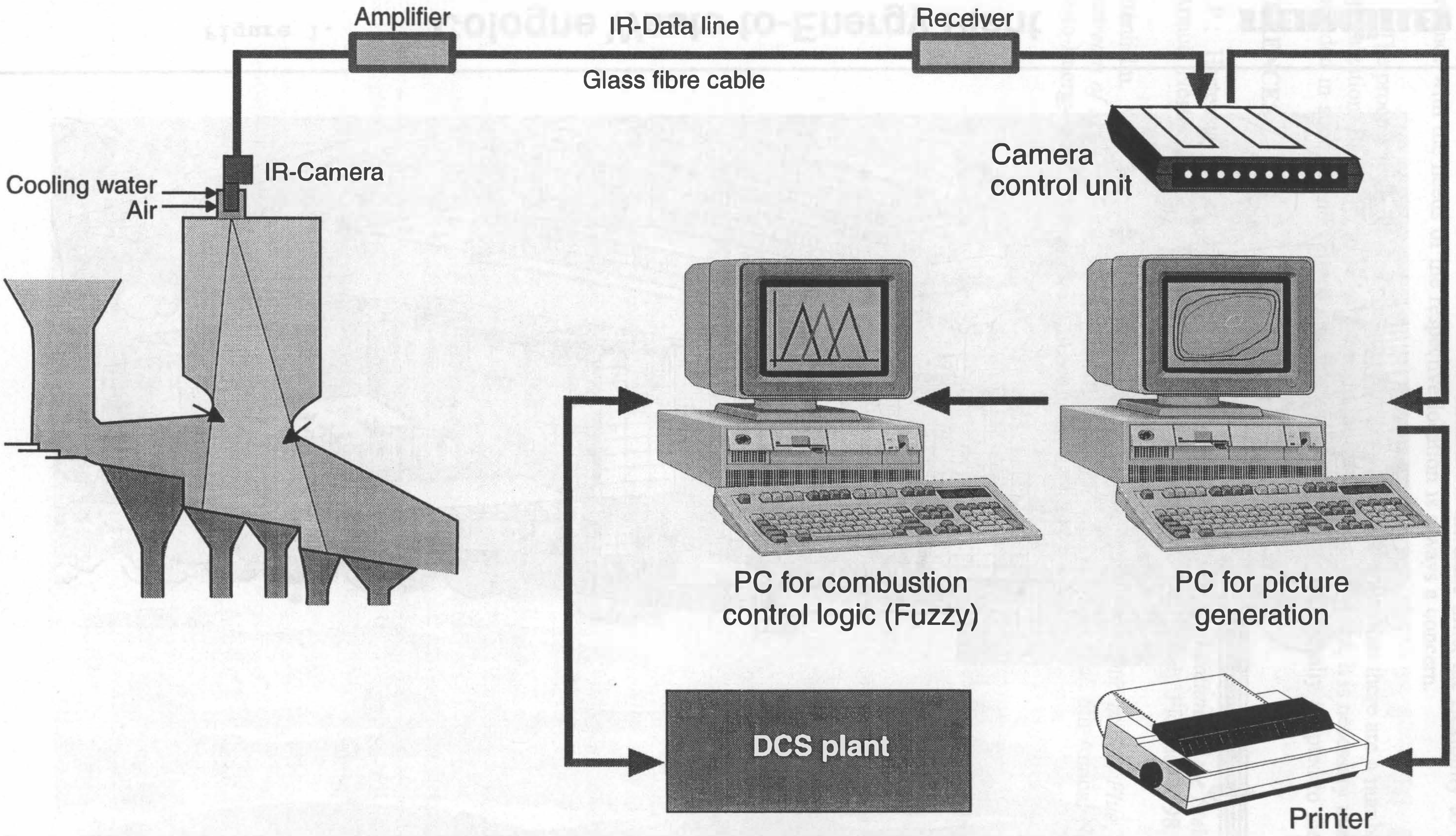


Figure 2.

**IR-Thermography
with Fuzzy Logic Control**

STEINMÜLLER

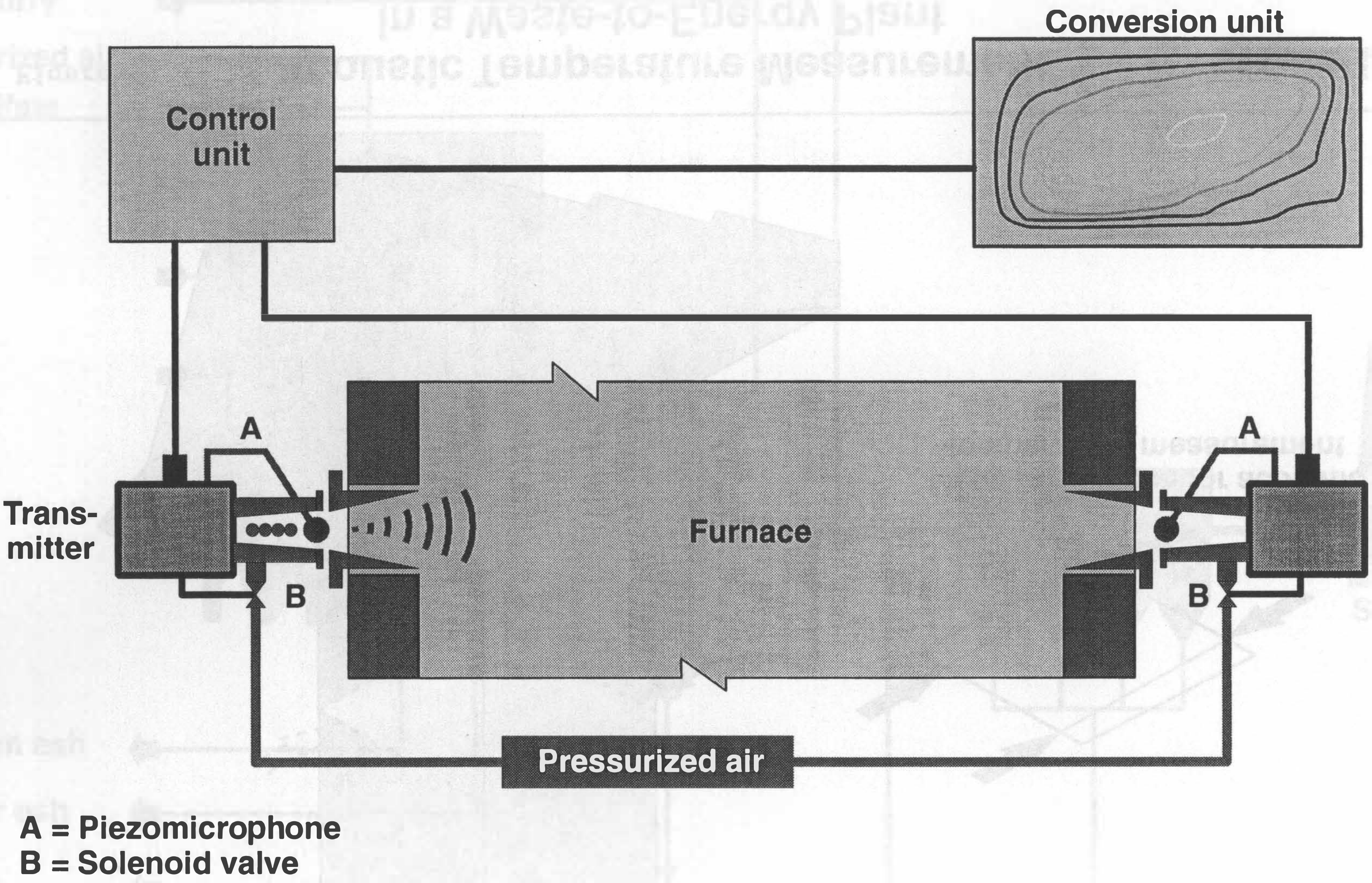


Figure 3. **Principle of Acoustic Temperature Measurement**

STEINMÜLLER

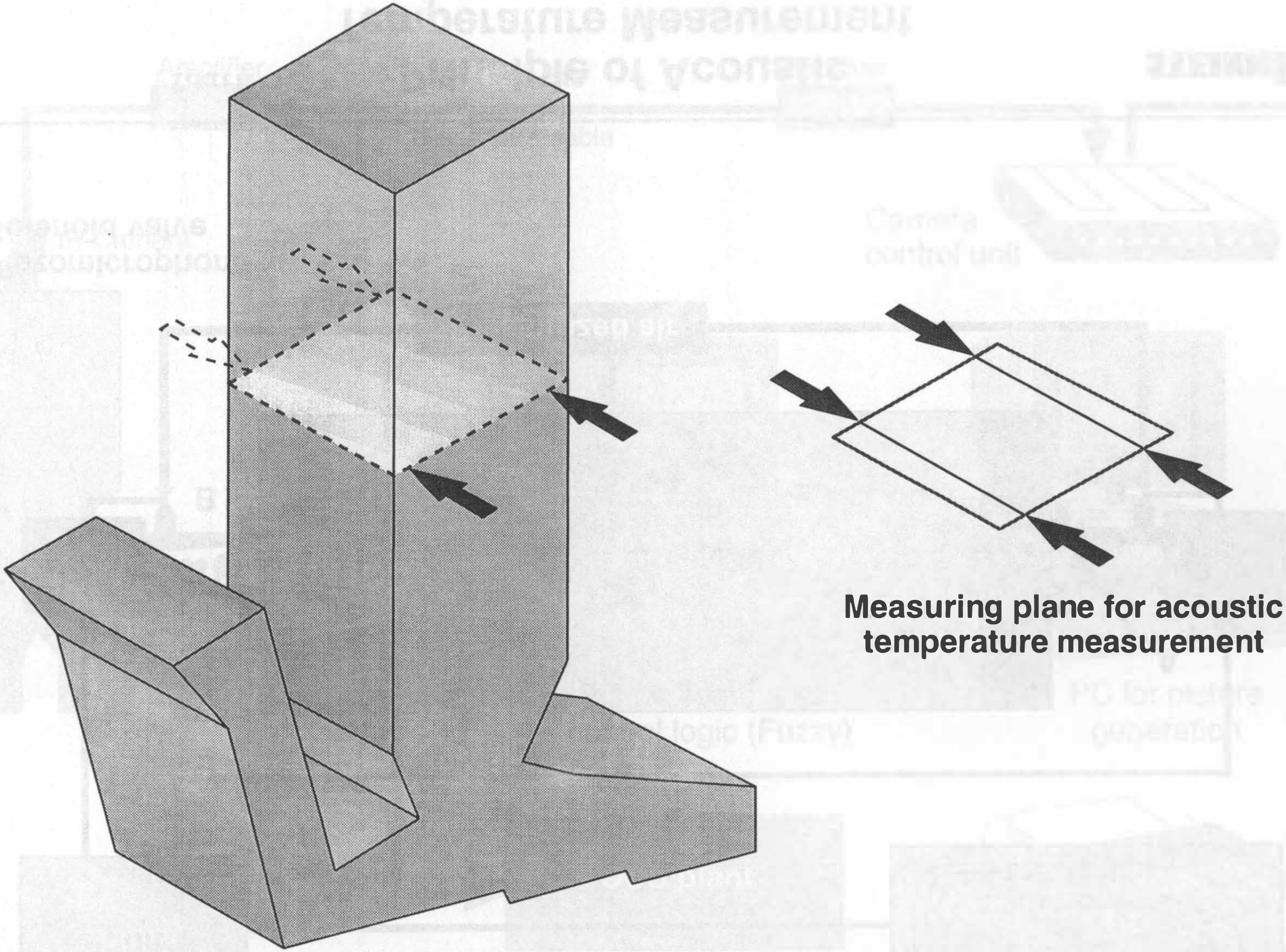


Figure 4. Acoustic Temperature Measurement in a Waste-to-Energy Plant

STEINMÜLLER

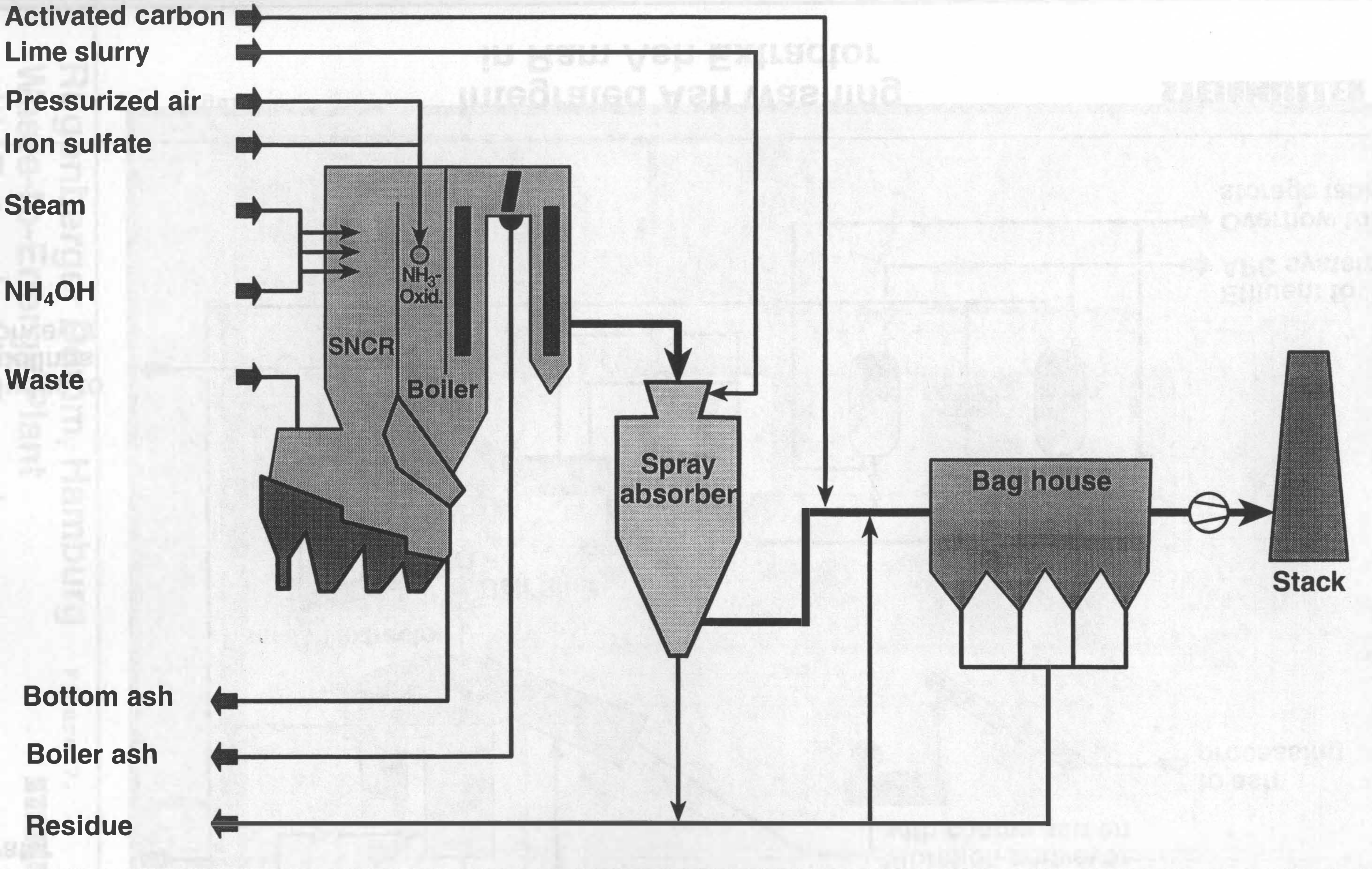


Figure 5. SNCR with Catalytic Oxidation of the NH_3 - Slip

STEINMÜLLER

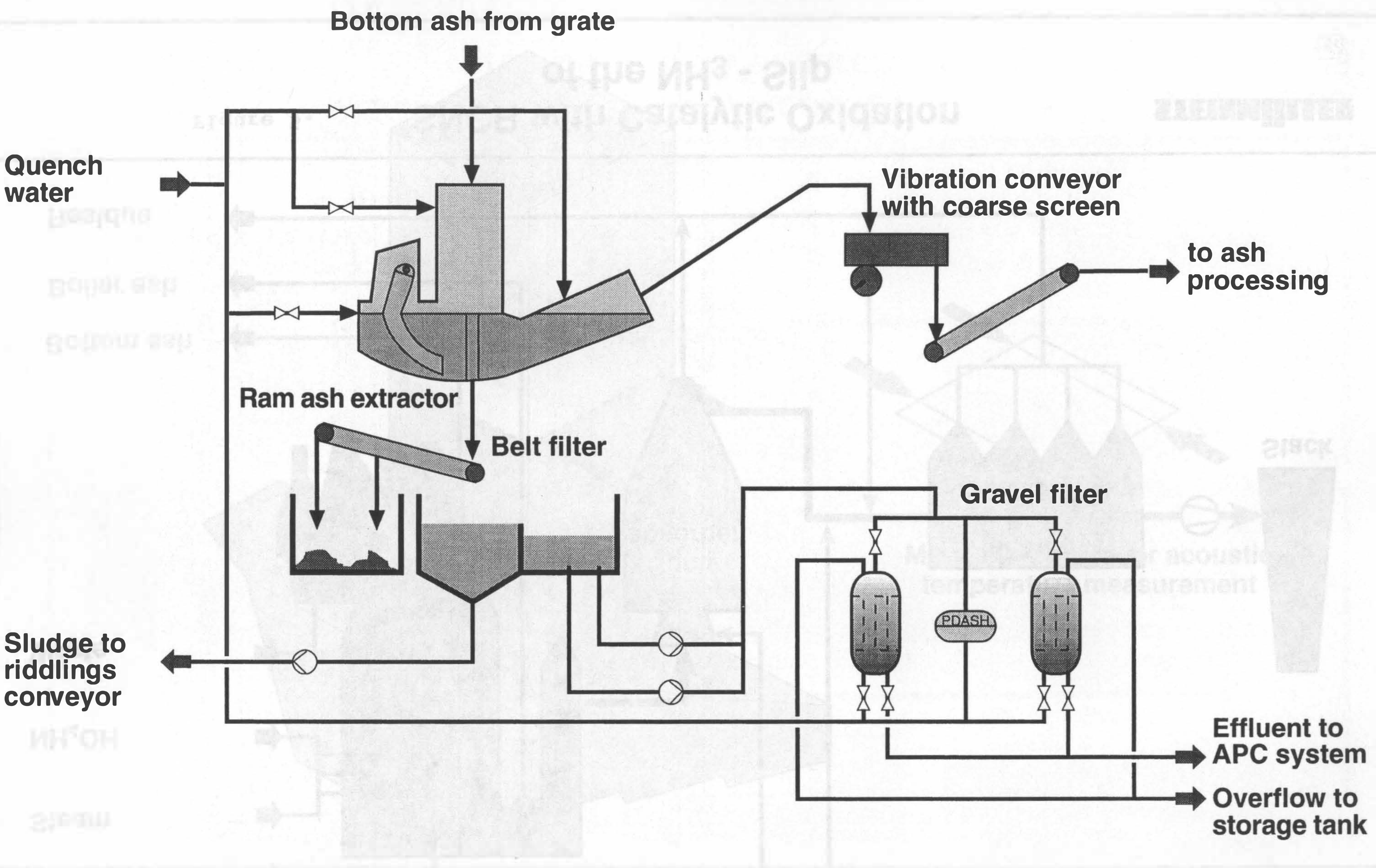
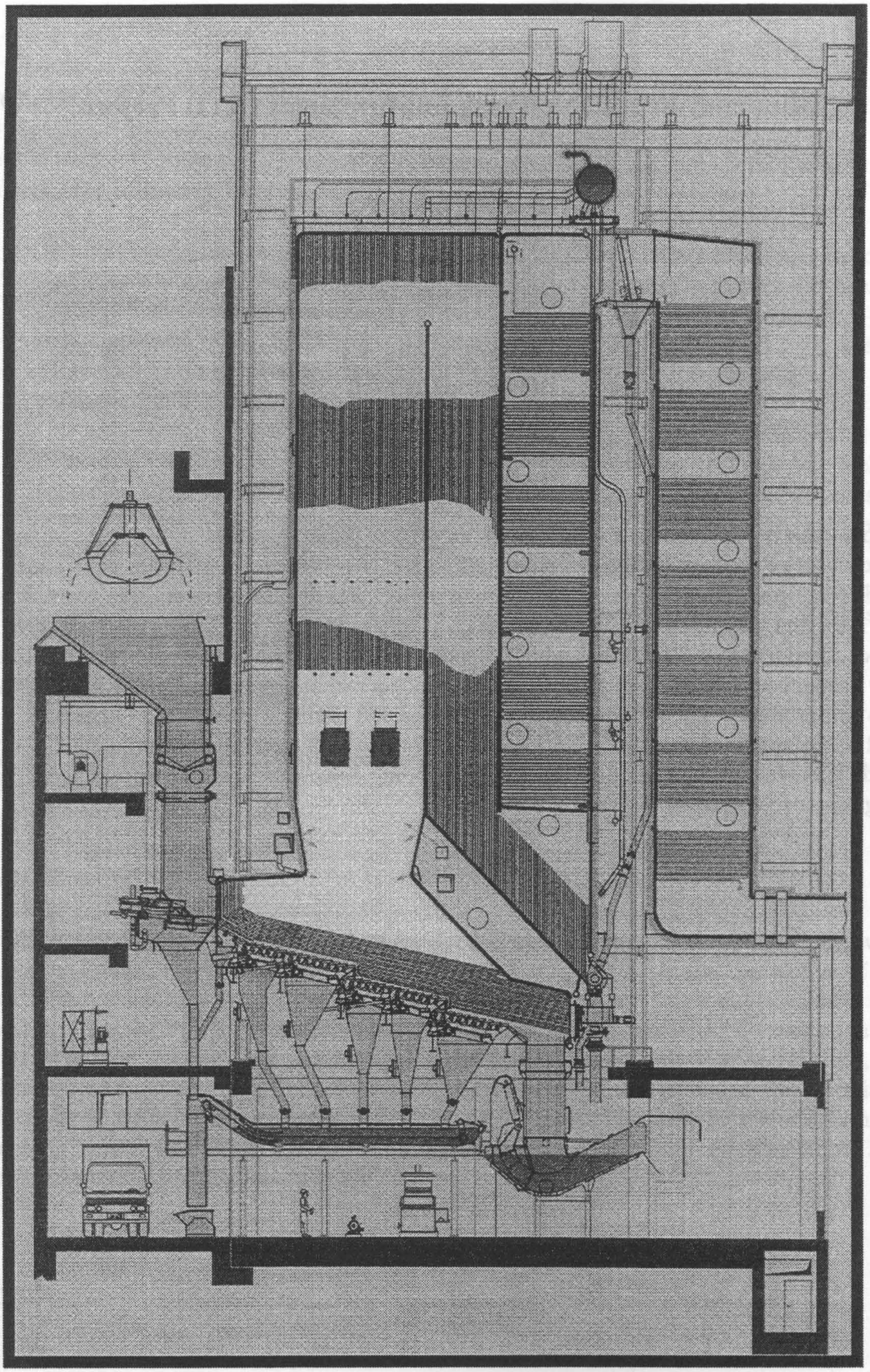


Figure 6. Integrated Ash Washing in Ram Ash Extractor

STEINMÜLLER



Rugenberger Damm, Hamburg Waste-to-Energy Plant with Extended Economizer

Figure 7.

STEINMÜLLER