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Evaluation of Design Practices

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EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

Duesseldorf-Flingern Plant
West Germany

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Volume 16

U.S. ENVIRONMENTAL PROTECTION AGENCY

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PREFACE

This trip report is one of a series of 15 trip reports on European waste-to-energy systems prepared for the U.S. Environmental Protection Agency. The overall objective of this investigation is to describe and analyze European plants in such ways that the essential factors in their successful operation can be interpreted and applied in various U.S. communities. The plants visited are considered from the standpoint of environment, economics and technology.

The material in this report has been carefully reviewed by the European grate or boiler manufacturers and respective American licensees. Nevertheless, Battelle Columbus Laboratories maintains ultimate responsibility for the report content. The opinions set forth in this report are those of the Battelle staff members and are not to be considered by EPA policy.

The intent of the report is to provide decision making information. The reader is thus cautioned against believing that there is enough information to design a system. Some proprietary information has been deleted at the request of vendors. While the contents are detailed, they represent only the tip of the iceberg of knowledge necessary to develop a reliable, economical and environmentally beneficial system.

The selection of particular plants to visit was made by Battelle, the American licensees, the European grate manufacturers, and EPA. Purposely, the sampling is skewed to the "better" plants that are models of what the parties would like to develop in America. Some plants were selected because many features envolved at that plant. Others were chosen because of strong American interest in co-disposal of refuse and sewage sludge.

The four volumes plus the trip reports for the 15 European plants are available through The National Technical Information Service, Springfield, Virginia 22161. NTIS numbers for the volumes and ordering information are contained in the back of this publication. Of the 19 volumes only the Executive Summary and Inventory have been prepared for wide distribution.

ORGANIZATION

The four volumes and 15 trip reports are organized the the following fashion:

ACKNOWLEDGEMENTS

We are pleased to acknowledge the very competent, earnest, and generous assistance which we received from the following without whose help this descriptive report and analysis would have been impossible:

- Stadtwerke Duesseldorf
  - Dr. Maruct, Member of the Board
  - Karl-Heinz Thoemen, Works Manager
  - Uwe Andresen, Assistant Works Manager
- Vereinigte Kesselwerke
  - Dir. Werner Schlottman
- Grumman Ecosystems, Inc.
  - Klaus Feindler
- Stadtreinung u. Fuhramt
  - Dir. Helmut Orth, Retired

SUMMARY

This 13-year old plant, Figure 3-1, is a pioneer in the sense that it utilizes a unique burning grate that was developed at Duesseldorf between 1961 and 1965. Also this full-scale plant was the first large application of this new method--the Duesseldorf roller grate, now used all over the world. It utilizes the slow rotary motion of six or seven horizontal drums to move and gently agitate the burning refuse on a downward sloping path through the furnace.

This single plant, enlarged in 1972, and anticipating a further expansion, is an obviously successful venture by the city of Duesseldorf and surrounding communities toward solving their solid waste problem.

Another unique feature of this plant is that for 13 years, it has been supplying 930 F (500 C) steam to its "parent" Flingern Power Plant. This has not been without its corrosion problems but the management and staff have experimented and developed corrective measures which have reduced their corrosion losses to within acceptable limits. In numerous publications, the plant manager has generously shared this experience with all who are interested.

The plant serves a population of 800,000 of these, 600,000 are in Duesseldorf. In 1976, it burned 284,185 tonnes (312,603 tons) and produced 564,091 tonnes (620,500 tons) of high pressure, 80 bar (1160 psig), high temperature, 500°C (932 F) steam for power generation and for making hot water for district heating. Baled iron scrap and sized ash is also sold from the residue. The net burning cost after allowing for all income is now averaging about 30 DM per tonne (11.43 per ton) in 1976.

During the visit, there was discussion of a sixth unit to be installed around 1980.

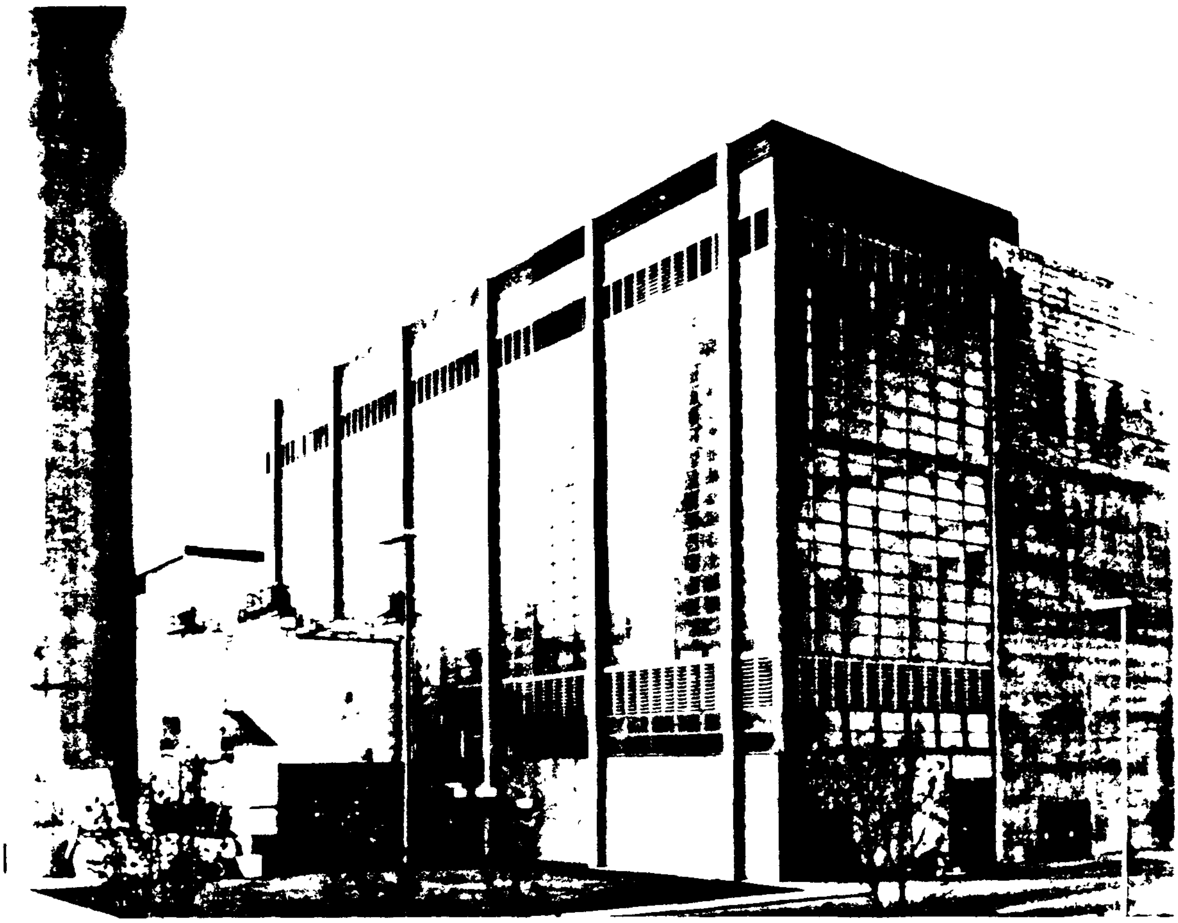


FIGURE 3-1. REFUSE INCINERATION PLANT AT DUESSELDORF

STATISTICAL SUMMARY

Community description:	
Area (square kilometers)	R = 20 km → 7,250 km^2
Population (number of people)	800.000 hab. (Duesseldorf: 600.000
Key terrain feature	Rhein Valley, flat
Solid waste practices:	
Total waste generated per day (tonnes/day)	778.6 t/d (1976)
Waste generation rate (Kg/person/yr)	0.973 (1976)
Lower heating value of waste (Kcal/kg)	1700 ↔ 2000
Collection period (days/week)	5
Cost of collection (local currency/tonne)	95 DM/tonne
Use of transfer and/or pretreatment (yes or no)	transfer: no – shredder / shear | yes
Distance from generation centroid to:	
Local landfill (kilometers)	10
Refuse fired steam generator (kilometers)	<7
Waste type input to system	MSW-Industrial-Bulky
Cofiring of sewage sludge (yes or no)	No
Development of the system:	
Date operation began (year)	1965
Plant architecture:	
Material of exterior construction	Concrete
Stack height (meters)	100 m
Refuse fired steam generator equipment:	
Mass burning (yes or no)	Yes
Waste conditions into feed chute:	
Moisture (percent)	25-28 Percent
Lower heating value (Kcal/kg)	1850 kcal/kg
Volume burned:	
Capacity per furnace (tonnes/day)	Furnaces 1 to 4: 240 t/d; Furnace 5:300
Number of furnaces constructed (number)	5

Capacity per system (tonnes/day)	1260 t/d
Actual per furnace (tonnes/day)	#1-4:8.5-10tphr/#5:12.5tphr
Number of furnaces normally operating (number)	4 out of 5
Actual per system (tonnes/day)	850-960
Use auxiliary reduction equipment (yes or no)	Yes
Pit capacity level full:	
(Tonnes)	4000
(m^3)	10'500
Crane capacity:	
(tonnes)	10t - Bucket capacity: 4 m^3
(m^3)	
Feeder drive method	#1-4: mechanical; #5: hydraulic
Burning grate:	
Manufacturer	Vereinigte Kessel Werke
Type	Duesseldorf roller grate
Number of sections (number)	Boilers No. 1-4: 7; Boiler No. 5: 6
Length overall (m) effective #1-4:16,57m	#5:14.21m
Width overall	3m
Drum diameter	1.5m
Primary air-max	75'000 Nm^3/h Boiler No. 5 40,000 Nm^3/h Boiler No.1-4
Secondary air-overfire air-max (m^3/min)	#1-4 - 200 m^3/min #5 - 250 m^3/min
Furnace volume (m^3) #1-4:167m^3 #5:297m^3	(without boiler volume)
Furnace wall tube diameter (mm)	#1-4: 70 #5 : 52
Furnace heating surface (m^2)	Boilers 1-4: 100m^2; Boiler 5: 146m^2
Auxiliary fuel capability (yes or no)	Yes
Use of superheater (yes or no)	Yes
Boiler	
Manufacturer	DUrr (1.2,5) - VKW 3,4 1-4:
Type	Steilrohrkessel
Number of boiler passes (number) #1-4:2	#5÷4
Steam production per boiler(kg/hr)	Boilers 1-4: 16/20x10^3 Boiler 5: 25/30x10^3
Total plant steam production (kg/hr)	89/110x10^3 kg/h = 89-110t/h
Steam temperature (°C)	480 -500°C
Steam pressure (design)	(1500 psia) 105/112 atm. - 1491-1590 psig

Use of feed water heater	Yes
Use of economizer (yes or no)	Yes
Use of air preheater (yes or no)	Yes
Use of flue gas reheater (yes or no)	No
Cofire (fuel or waste) input	No
Use of electricity generator (yes or no)	In neighboring plant
Type of turbine	BBC-HP; AEG-LP
Number of turbines (number)	2+2
Steam consumption (KS/KWh)	at 4,
Electrical production capacity per turbine	HP-13+32 MW LP-30+53 MW
Total electrical production capacity	125 MW
Turbine back pressure (kg/m^2)	
User of electricity ("Internal" and/or "External")	External

Energy utilization: Electricity generation and District Heating

Medium of D-H energy transfer	Hot water
Temperature of medium (°C)	Winter: 130°; return 70°C Summer: 80°; return 65°C
Customers/receiving energy (number)	132
Pressure of medium (bar)	8-16
Energy return medium	Hot water

Pollution control:

Air:

Furnace exit conditions

Gas flow rate (Nm^3/hr)	#1-4:45000, #5:60000
Furnace exit loading (mg/Nm^3)	11-13

Equipment:	
Mechanical cyclone collector (yes or no)	No
Electrostatic precipitator (yes or no)	Yes
Manufacturer	Lurgi/Rothemuhle
Inlet loading on precipitator (mg/Nm^3)	5,000-15,000
Exit - loading on precipitator (mg/Nm^3)	36-85
Legislative requirement (mg/Nm^3)	100
Scrubber (yes or no) *	No
Inlet loading:	
H Cl (mg/Nm^3)	--
H F (mg/Nm^3)	--
Exit loading:	
H Cl (mg/NM^3)	7.5 mg/Nm^3 at the exit
H F (mg/Nm^3)	--
Legislative requirements (mg/Nm^3)	HCL 100 mg/Nm^3 - HF-5 mg/Nm^3 CO-1s/Nm^3
Other air pollution control equipment (yes or no)	No

Water:

Total volume of waste water (liters/hr)	50-70x10^3 l/m
Ash:	
Volume of ash (tonnes/day)	300-385
Volume of metal recovered (tonnes/per working day)	40

* However, if a 6th line is installed, scrubbers may be required on all six units, #1-5 for the first time.

DEVELOPMENT OF THE SYSTEM

Organized waste management by the city of Duesseldorf began in 1862. As early as 1897, the growing problems with solid waste disposal led to some consideration of incineration.[1] However, not until 1957-1958 did an active search begin for some "new way" to process solid wastes. In 1960, it was decided to erect an experimental heat-recovery type of furnace in the existing coal-fired Flingern municipal power plant near the center of the city.

The plant is owned by "Das Stradtreinigungs und Fuhramt (Department of Sanitation and Streets) of which Helmut Orth was the Director prior to his recent retirement. That department has assigned operation of the Müllverbrennungsanlage (MVA) (Refuse Buring Plant) to the Stadtwerke Düsseldorf AG", the utility company for Düsseldorf, Dr. Marnet, member of the board and department head of the department for electricity generation is the legal operator.

COMMUNITY DESCRIPTION

Geography

Duesseldorf is a densely populated, highly industrialized city of about 600,000 people located on the very busy Rhine River. The terrain is very flat and many smaller industrial cities are located nearby along the river. Land costs are very high.

Government and Industry

Duesseldorf is a major industrial center and river port with a broad variety of manufacturing activities.

SOLID WASTE COLLECTION PRACTICES

Solid Waste Generation and Collection Activities

Over the more than 100 years that Duesseldorf has been collecting and disposing of community refuse, the methods and equipment for collection have evolved into a variety of vehicles. Outside of Duesseldorf, a population of over 200,000 are served in suburbs and in towns within a 20-km (12 mile) radius, as shown in Figure 3-2. In 1976, the daily per capita waste generation rate was 0.973 kg per person (2.1 lb). Table 3-1 shows the waste characteristics and flow for 1975.

Solid Waste Transfer and/or Pretreatment

Transfer stations are not used. Originally the only pretreatment arranged was a Lindenmann shear for bulky waste only. In 1972, when Unit No. 5 was installed, a 45 tonne/hr (49 ton/hr) Lindenmann shredder was installed to reduce the large amount of cardboard boxes and similar shreddable bulky waste that could not be cut up by the shear. (Lack of capacity)

Solid Waste Disposal

Plant residue and noncombustibles tabulated in Table 3-1 are sent to two landfills--Hamm and K31.

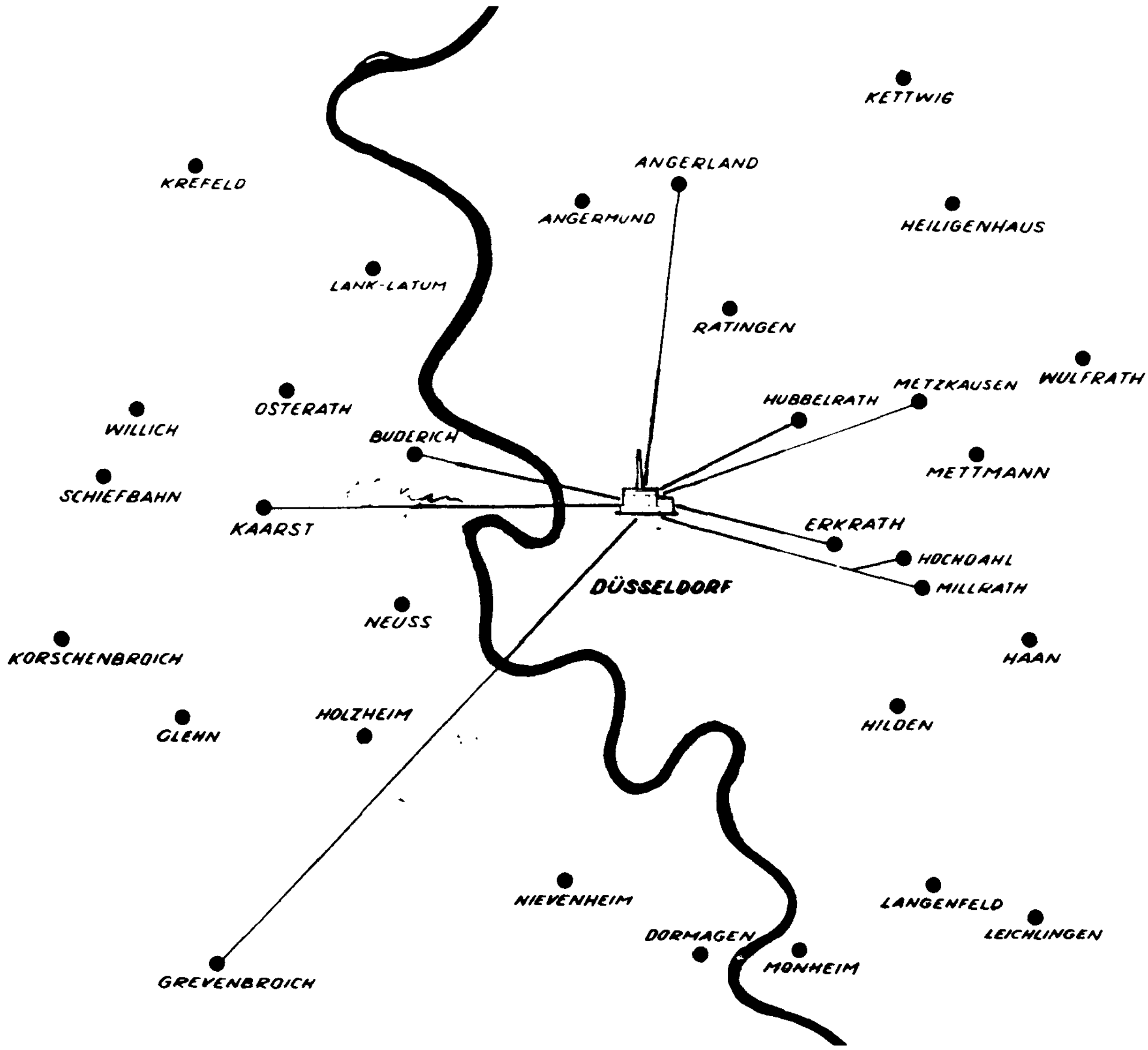


FIGURE 3-2. WASTE COLLECTION AREA SERVED BY DUESSELDORF PLANT[1]

TABLE 3-1. REFUSE COLLECTION AND DEPOSITING IN DUESSELDORF, 1975, TONNES*

	Incineration	Landfill/Hamm	Landfill, K-31
Household Wastes, 110 liter containers	128,872.51	16,431.44	--
Household Wastes, 1,100 liter containers	42,586.82	854.32	--
4.4 cbm containers	11,590.67	--	--
6.0 cbm containers	1,769.70	--	--
8.0 cbm containers	6,208.64	--	--
Fairgrounds	2,355.25	--	--
Supermarkets	2,290.10	--	--
Karlplatz	931.33	--	--
Special Waste	110.03	1,976.00	--
Bulky Waste	6,464.49	207.00	1,727.09
Tires	1,090.03	--	--
Household Waste From Outside Duesseldorf	30,557.04	--	--
Bulky Waste	2,549.12	--	--
Industrial Waste From Duesseldorf Plus Other Non-Combustible Waste	36,187.71	--	4,125.86
Bulky Industrial Waste	11,357.59	--	--
Rubbish	10,969.14	9,130.00	12,423.19
Oil polluted soil	1,668.29	--	--
Agricultural Refuse	--	--	24,895.17
Combustible Waste	297,358.36	28,599.26	43,171.32
Building Construction Waste			60,718.65
Excavated Earth			12,009.92
Dust			469.00
Foundry Sand			6,510.99

* Data provided by plant manager.

TABLE 3-1. (Continued)

Rubbish			4,252.50
Glass			5,010.00
Ash From Waste Burning			74,299.87
Industrial Wastes			3,237.73
Total Non-Combustible Wastes			166,508.68
To K-31 Landfill	43,171.32		
Non-Combustibles	166,508.68		
Total Non-Combustible	209,680.00		
Total Fired	297,358.56		
Landfill Hamm	28,599.26		
Landfill K-37	43,171.32		
Non-Combustible Waste	166,506.68		
Total	535,637.82		
Combustibles to Plant	297,358.56		
Discard to Hamm Landfill	28,599.26		
Discard to K-31 Landfill	43,171.32		
Total	369,129.14	Total Non-Combustible	209,680.00
Deductions	24,895.17	To Hamm Landfill	28,599.26
	344,233.97		
Total Refuse	535,637.82		
Amount Burned	297,358.56		
	238,279.26	Ash Not Sold	40,282.49
1975	344,233.97	Discarded Ash	15,579.22
	319,621.62	Total Ash	55,861.71
	24,612.35	Total Non-Combustible	294,140.97

REFUSE-FIRED STEAM GENERATOR EQUIPMENT

Six to 7,000 tonnes of refuse are delivered to the pit per week by 700 to 800 public and private trucks between 7:00 a.m. to 2:00 p.m., 5 days per week. On a 7-day week basis, hospital and hotel wastes are received.

A 15 tonne/hr shear is available in a separate building to cut up bulky wastes and since May, 1973, a 45 tonne/hr shredder has been used to shred bulky wastes. It will be explained later that the plant management feels that the concentration in the pit of this highly combustible, dry, shredded waste has been a major cause of high-temperature corrosion in the newest boiler, No. 5, which appears to receive most of that waste.

Figure 3-3 shows the plant property which is located in a concentrated industrial area well inside the city.

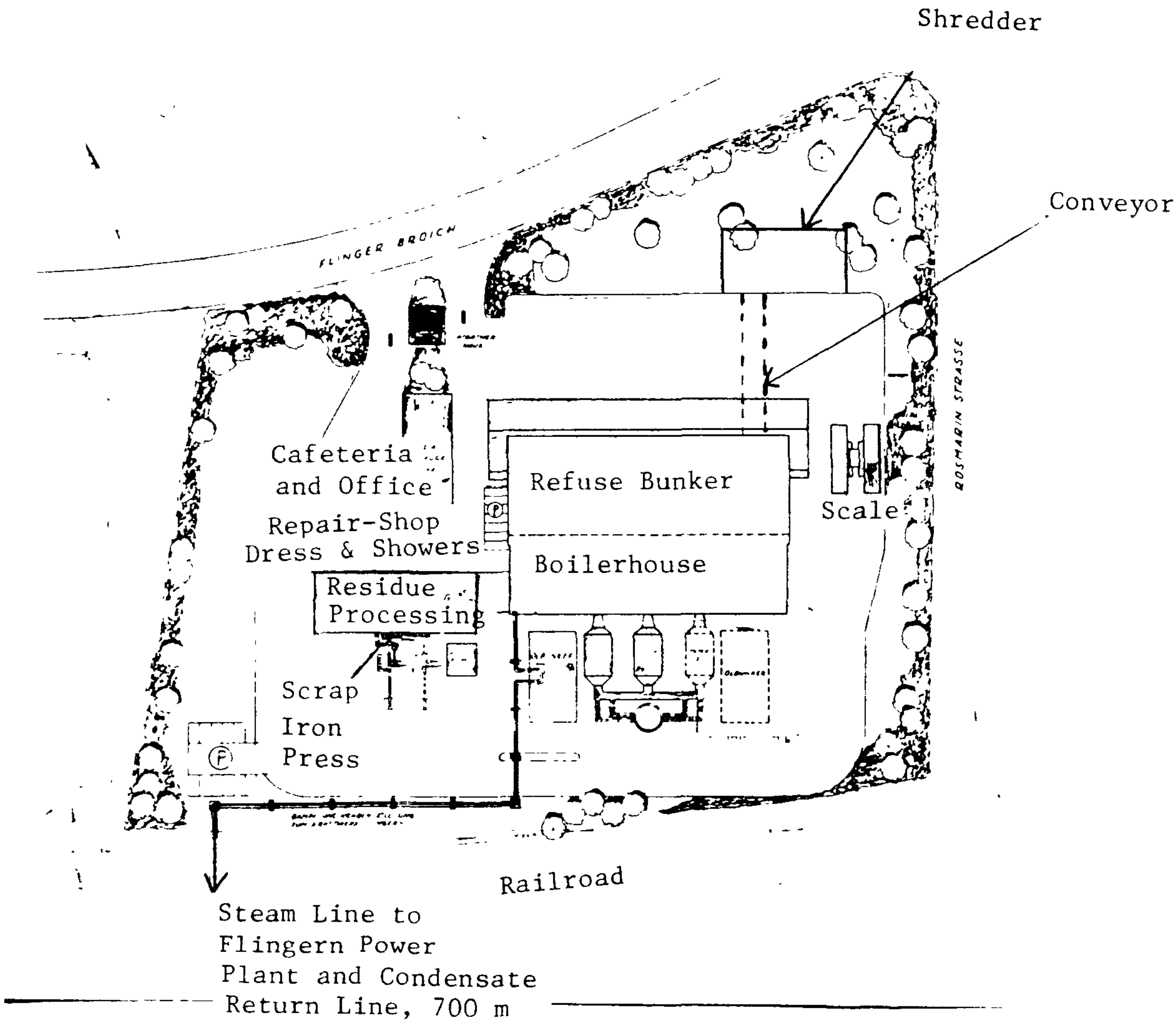
Figure 3-4 shows a cross-section of the plant as it was built in 1965.

The weigh scale is to the right of Figure 3-3. Two scales are provided--one on each side of the scale building--so that two trucks can be weighed simultaneously. The scales were built by Schenck of Darmstadt. Normally there is one scale operator. At peak times, there are two. Peak times are from 8:30 a.m. to 10:30 a.m., 12:00 to 1:30 p.m., and 2:30 p.m. to 3:00 p.m.

The scale reading and tare are punched automatically on data cards. Also, an automatic typewriter logs the readings.

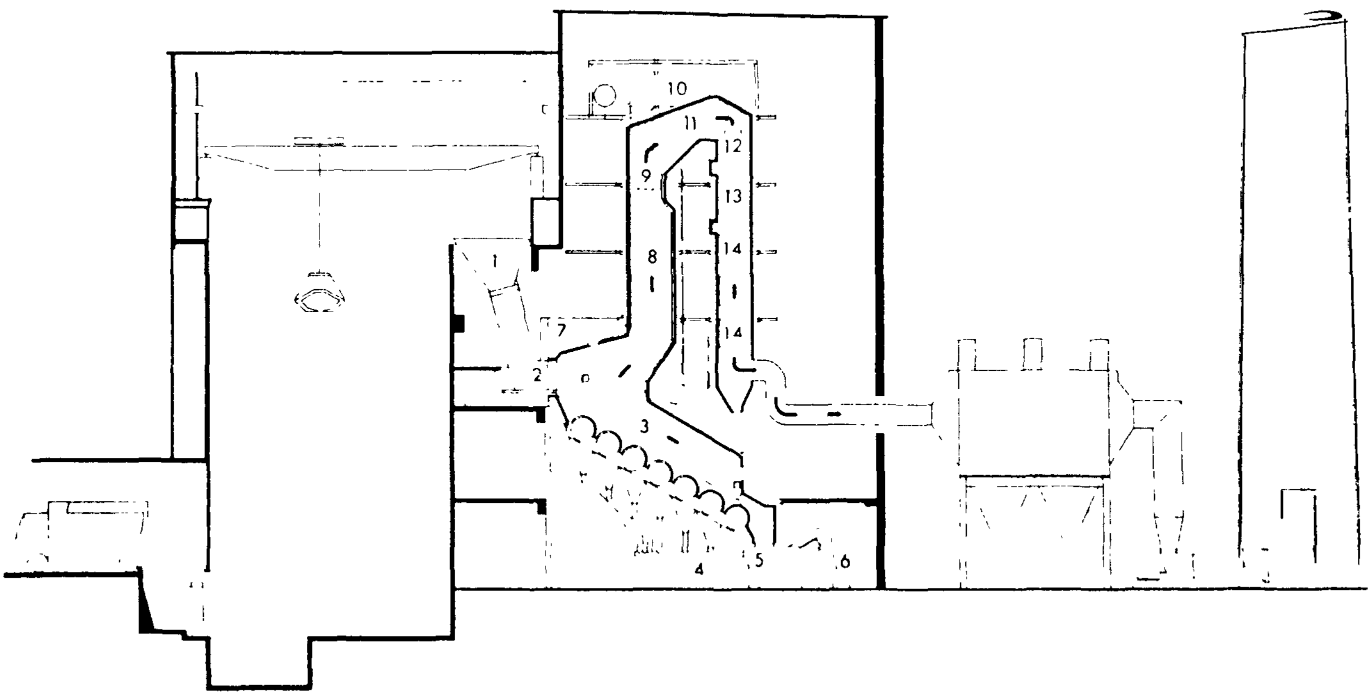
The scale service has been good with little maintenance. Calibrations are made every 3 years. The scale data-recorder has caused difficulty. The electrical system requires repair 10 times per year.

When the scale operator observes bulky waste in a truck, he directs it to either the shredder or the shear. The standard refuse container in Duesseldorf takes up to 0.6 m (2 ft) pieces; larger pieces are cut or shredded. The Lindenmann shear is a hydraulically driven knife and bar machine usually operated 3 to 4 hours per day. At times of heavy use, the operator is assisted by a scale operator. The shear produces pieces about 0.6 m by 0.5 m (2 ft by 1.6 ft). Rubber tires are usually cut to 0.25 m square (0.8 ft). Shear load is indicated by the current input to the hydraulic-driven motor.



Total Area:	30,831 sq. meters
Buildings:	7,000 sq. meters
Streets:	15,831 sq. meters
Trees, Shrubbery, Grass	8,000 sq. meters

FIGURE 3-3. PLAN OF DUESSELDORF WASTE-TO-ENERGY PLANT
(COURTESY STADTWERKE DUESSELDORF)



1 Refuse feed hopper
2 Refuse push feeder
3 "Dusseldorf System" roller grate
4 Humidifying worm conveyor
5 Wet type ash extractor
6 Ash belt conveyors
7 Roof light-off burner
8 Evaporator heating surfaces
9 Platen superheater
10 Nos 1 and 2 spray attemperators
11 No 2 primary superheater
12 No 1 primary superheater
13 Evaporator coils
14 Continuous loop economizer

FIGURE 3-4. CROSS SECTION OF DUESSELDORF PLANT (Units 1-4) (COURTESY VEREINIGTE KESSELWERKE)

Shear stroke can be manually adjusted by the operator. Operating time is recorded. Shear blades are turned over every 3 months and are replaced once per year. The hydraulic seals must be replaced 1-2 times per year

The Lindemann shredder was added in May, 1973. It is a horizontal-shaft, belt-driven machine which operates about 6 hours per day. No one is permitted in the shredder building during operation owing to explosion hazards. The size of pieces produced is relatively large--0.3 m by 0.5 m (1 ft by 1.6 ft)--although rubber tires may pass through essentially intact. The output is conveyed to the main plant pit by a belt conveyor. Maintenance on the shredder is minor which the management attributes to the relatively large size of the product. The first set of shredder hammers lasted 4,000 hours during which 40,000 tonnes (44,000 tons) were shredded. The second set lasted 3,000 hours.

Much more difficulty has been experienced with the feed and output conveyors for the shredded refuse. The oil mist lubrication for the conveyor has been ineffective.

Figure 3-5 shows the main bunker which has a storage capacity of 10,500 m^3 (370,313 ft^3 or 13,734 yd^3). At a compressed and settled density of 645 lb/yd^3 (0.383 $tonnes/m^3$), this represents a storage volume of 4,022 tonnes (4,424 tons), about 3 days supply. Fire control is by means of six nozzles at the operator's level plus a spray system.

There are three „Schiess" cranes (now part of Demag), 120 tonnes or (132 tons) each. One crane is stored as a spare on a track in a loft above the boiler top level. Also, the crane can be quickly hoisted onto this storage track for repairs. One of the two crane operator's posts can be seen on the left in Figure 3-5. Both cranes operate simultaneously during the day, alternately at night.

Each crane bucket is the polyp type with a capacity of 4 m^3 (141 ft^3). Figure 3-5a shows a new bucket in preparation for installation.

For boiler tests, the crane motor electrical input was calibrated in terms of weight lifted. During the tests, this current was recorded continuously. In routine operation, the crane operator records the number of bucket loads charged to each furnace per shift. From this, an approximate average furnace load is calculated.

FIGURE 3-5. MAIN STORAGE PIT. THERE ARE TWO CRANE OPERATORS OPERATING PULPIT FOR ONE IS AT UPPER LEFT (Courtesy Vereinigte Kesselwerke AG)

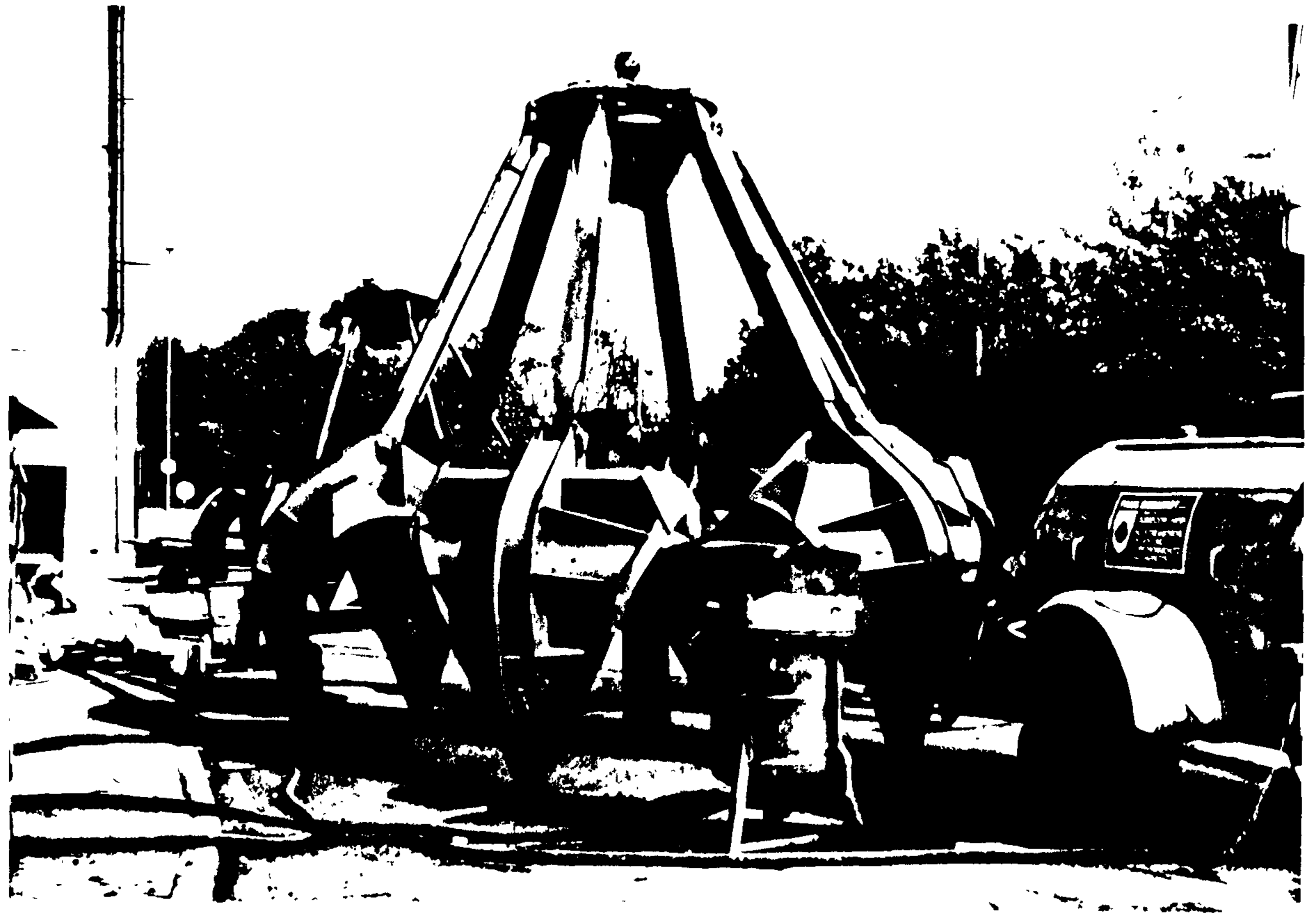


FIGURE 3-5a. NEW POLYP BUCKET BEING PREPARED FOR INSTALLATION (Battelle Photo)

The lifting cables on the cranes last about 6 months. The bucket-closing cables last on the average 4 to 5 weeks although at times, they may fail in 3 days. On weekends, cable inspection may reveal near failure which is immediately remedied.

Furnace Hoppers and Feeders

Some modification of the original 5 m by 5 m (16.3 ft by 16.3 ft) hoppers has been required to prevent bridging in the pyramidal hopper. The remedy was to raise one side of the sloping hopper wall so that less material could crowd downward into the feed chute. This crowding caused the bridging. Also, the feed chute, 3 m by 1.8 m (10 ft by 5.9 ft), is tapered outward from top to bottom at the rate of 150 mm (5.9 in) in 5 m (16.3 ft) to relieve the tendency to jam in the chute. Two years ago, the height of the opening (see Figure 3-4), where the refuse is pushed from the bottom of the chute into the furnace, was reduced somewhat on three of the boilers to prevent burnback. Also, about 1 year ago, water cooling was added to the lower 2.5 m (8 ft) on some of the feed chutes. On those chutes, which are not water cooled, burnback during shutdown is prevented by use of guillotine doors covering the opening between furnace and chute.

Four of the reciprocating refuse feeders are mechanically driven and one drive is hydraulic. They feed horizontally under the automatic control of boiler steam flow but are limited by furnace temperature and excess oxygen. If temperature is too high or oxygen is too low, feed rate is reduced. The reciprocating feeder plate is water cooled. The forward stroke is faster than the return stroke. Operators prefer the four mechanically driven feeders because they require less maintenance than the hydraulic drive. Also, any hydraulic fluid leakage constitutes a fire hazard. The feeders used were developed at this plant.

Figure 3-6 is a side view of Boiler No. 4. The feed chute and feeder are at the right.

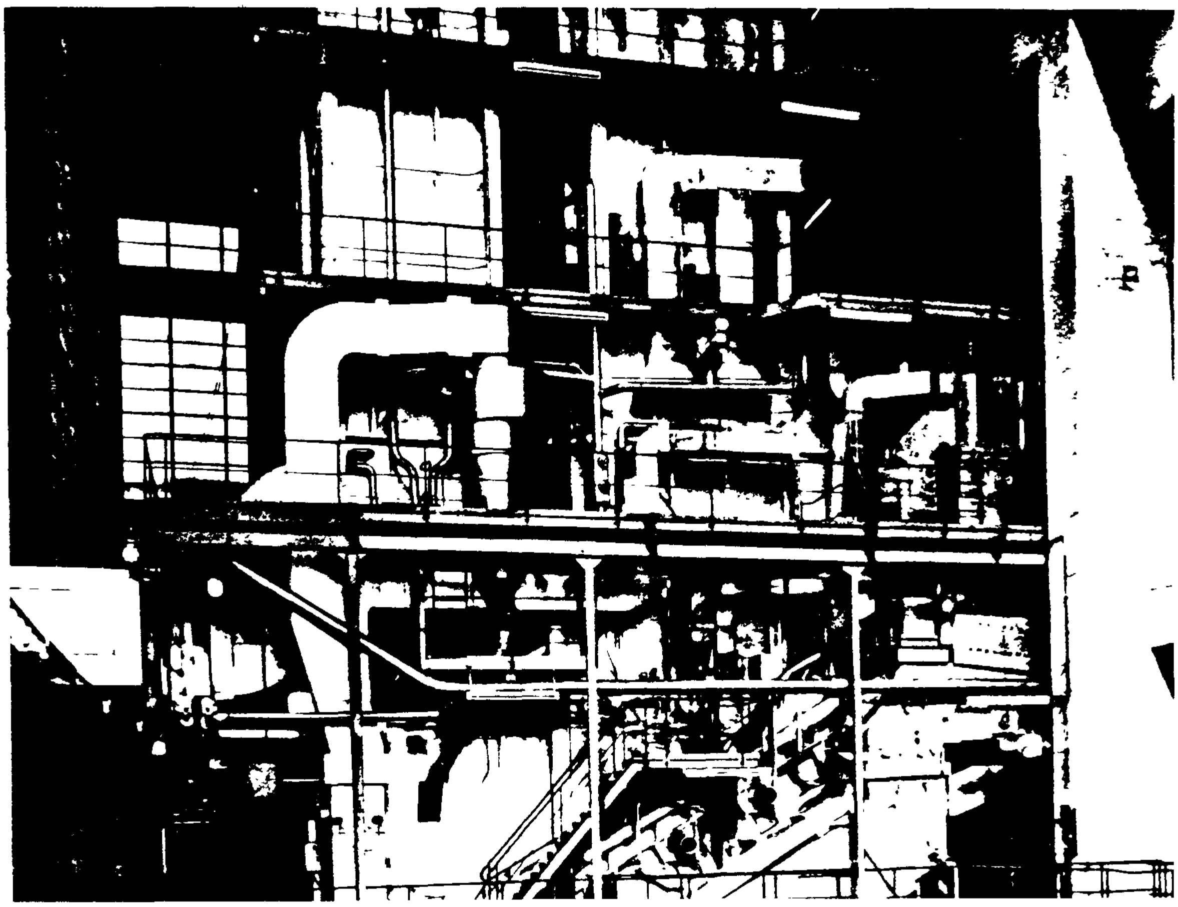


FIGURE 3-6. SIDE VIEW OF BOILER NO. 4 (Courtesy of Vereinigte Kesselwerke)

Burning Grate

Figure 3-7 shows the essential characteristic of the "walzenrost" (roller grate) which was developed in 1961 at the neighboring Flingern Power Plant, using a four-roller pilot grate which has since been dismantled. It is manufactured by the Vereinigte Kesselwerke in Duesseldorf and is generally known as the "Duesseldorf Grate". It provides a sloping fuel bed as do most European mass-burning grates for refuse. But instead of using oscillating or reciprocating grate bars to agitate the burning material and to move the incombustible residues down the slope, the walzenrost moves the bed by slow rotation of the 1.5 m (4.92 ft) diameter drums which are formed of cast iron grate sections. Thus, there is opportunity for a slow tumbling action of the refuse which helps to keep the fibrous mass loose, thus allowing for upward flow of primary air throughout the bed.

The drums rotate at an adjustable speed of about three to six revolutions per hour. Instead of being continuously exposed to the hot fuel bed, each grate bar rotates through a cool zone about half of the time. Thus, for minor repairs to the grates, the temperature on the underside of the grate is low enough to enable workmen to repair it while the unit is on line.

Each grate roll is formed of 10 sections, each of which contains 60 curved grate bars. The bars at each side which rub against the air seal plates are cast of chrome-nickel alloy to resist abrasion. Out of a total of 600 bars per roll, 20 are cast alloy. Boilers No. 1-4 have seven rolls each but in No. 5 and later designs, there are six rolls per furnace.

The gap between adjacent rolls is filled by a cast iron wiper bar. This bar is strong enough to shear off refuse that may become attached to the grate. The only grate bar failures that have been experienced was the replacement of the first roll in two different furnaces when scrap containing considerable magnesium was charged. In one case, 20,000 dry cells containing magnesium damaged the first roll so that replacement was necessary. Similar loss of the first roll has occurred on three separate occasions since 1965. The remainder of the grate rolls have operated 30,000 hours without major repairs. In 1976, total down time for repairing all 34 rolls in the plant was 650 hours. Some rolls were repaired simultaneously during this period.

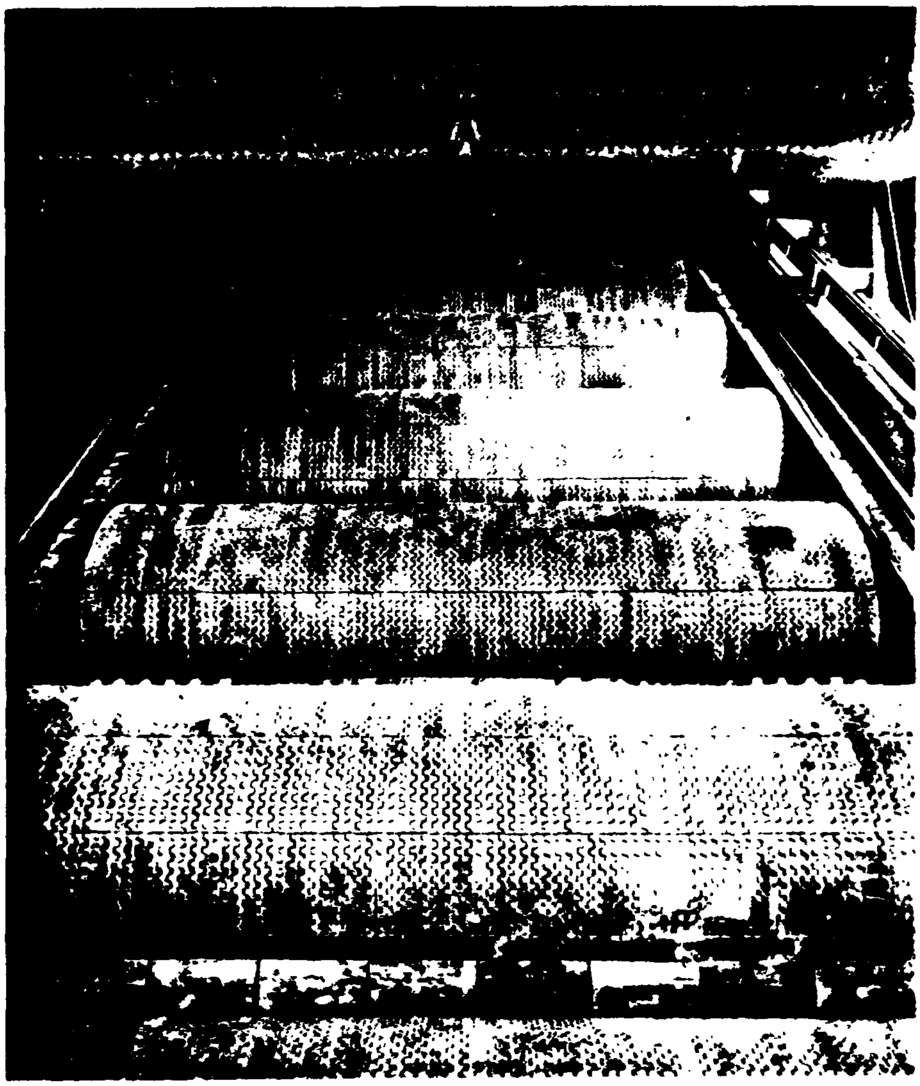


FIGURE 3-7. SIX DRUM WALZENROST (ROLLER GRATE); ALSO COMMONLY KNOWN AS THE DUESSELDORF GRATE. NOTE THE CAST IRON WIPER SEALS BETWEEN ADJACENT ROLLS WHICH PREVENT LARGE PIECES OF REFUSE FROM FALLING OUT OF THE FURNACE (Courtesy of Vereinigte Kesselwerke)

The wiper seals are repaired three times a year. Normal wear of the seal gradually widens the gap which allows larger and larger pieces of residue to fall through. A screw conveyor removes such residue from underneath the grate.

The hollow steel roller shafts have never been replaced. Asbestos air seals at each end of the shaft require replacement every 5 or 6 years.

Each roller constitutes a separate supply zone for primary air. The air enters the interior of the roll from both ends and flows through the many small gaps between the interlocking grate bars. The amount of air flow through each roll can be adjusted.

As the burning refuse moves down the slope, the rotative speed of each successive roll is adjusted so as to keep the fuel bed thickness approximately uniform.

This is an extremely rugged type of grate. The first roll is subject occasionally to severe impact from heavy objects being fed in by the feed ram and then dropping 1.8 m (5.9 ft) to the first roll. No damage has occurred as a result of such impacts.

Furnace Wall (Combustion and First Pass Radiation Chambers)

The five furnaces at this plant comprise an interesting example of the evolution of water-tube wall furnaces for mass burning over the past 12 years. When the first pilot furnace was built in 1961, the use of water-tube walled furnaces for refuse was still in its infancy. There were good reasons for that. The heat value of European refuse was very low. This was caused by three factors. Many homes used coal for heating and the resulting ash and clinkers were discarded with other household refuse. Probably also dry, combustible wastes tended to be burned in the domestic coal stoves for their heat value. Thus, the moisture in any remaining household wastes, such as food scraps, tended to raise the moisture content of the collected waste. In addition, Europeans economized in their shopping by use of a minimum of paper bags and other packaging. Then in the 1950's, many homes were converted to oil, thus eliminating much ash from municipal refuse. Also, paper packaging came into widespread use and the heat value of European refuse increased rapidly. Table 3-2 shows that from 1961 to 1975 at the Duesseldorf plant, the average lower heat value of refuse increased 70 percent, 4,292 kJ/kg to 7,314 kJ/kg (1,025 kcal/kg to 1,747 kcal/kg) [1,845 Btu/lb to 3,145 Btu/lb].

Thus, so long as wet, high-ash refuse often made combustion very difficult, designers were understandably reluctant to depart from the use of hot refractory-walled furnaces. However, as the heat value of refuse increased, furnace refractories were damaged by excessive furnace temperatures and the merits of water cooling the furnace and thus of adding it to the heat recovery loop became more and more attractive. However, the pilot plant at Duesseldorf, burning 8 tonnes per hour, utilized an old refractory-walled furnace, shown in Figure 3-8, which had originally burned coal on a traveling grate at the Flingern Power Plant. This pilot unit was operated intermittently for a total of 22,000 hours from 1961 to 1965 and provided the design basis for a plant started up at Rosenheim in 1964, and for the first four full size units at Duesseldorf--the first of which was started in November, 1965.

For the reasons cited earlier, when the design transition was made in 1964-1965 from the old refractory-walled pilot furnace to the new, full-scale units, No. 1 through 4, there was an understandable reluctance to use a fully water-tube walled furnace. Although the lower heat value of Duesseldorf refuse shown in Table 3-2 had risen to 1,220 kcal/kg (5,108 kJ/kg [2,196 Btu/lb] by 1963, that was still a relatively low level; hence, the need for some refractory in the main furnace to reflect heat to the raw refuse so as to facilitate rapid ignition and burning.

Accordingly, the front and rear water tube walls of the furnace itself in Units No. 1 through 4 were protected by a 50 percent aluminum oxide refractory curtain 250 mm (10 in) thick and spaced by a dead air space 50 mm (2 in) wide in front of the vertical wall tubes. The tubes are 70 mm (2.75 in) diameter with 5 mm (0.2 in) wall thickness. The distance between tubes is about 70 mm.

This type of unique wall construction was not used in Furnace No. 5 built in 1972, which will be described later.

TABLE 3-2. HEATING VALUES FOR MIXED MUNICIPAL REFUSE IN REFUSE POWER PLANTS (COURTESY OF KLAUS S. FEINDLER)(1)(5)

Year	Duesseldorf(2) Minimum Btu/lb. (kcal/kg)	Duesseldorf(2) Average Btu/lb. (kcal/kg)	Duesseldorf(2) Maximum Btu/lb. (kcal/kg)	Stockholm(3) Average Btu/lb. (kcal/kg)
1961	--	1,845 (1,025)	--	--
1962	--	1,530 (850)	--	--
1963	--	2,196 (1,220)	--	--
1964	--	--	--	3,546 (1,970)
1965	--	--	--	3,942 (2,190)
1966	--	2,468 (1,371)	--	4,050 (2,250)
1967	--	2,621 (1,456)	--	--
1968	--	2,792 (1,551)	--	--
1969	--	2,882 (1,601)	--	--
1970	--	2,948 (1,638)	--	--
1971	--	3,087 (1,715)	--	4,545 (2,525)
1972	2,911 (1,617)	3,164 (1,758)	3,299 (1,832)	4,950 (2,750)
1973	2,803 (1,557)	3,037 (1,687)	3,242 (1,801)	4,680 (2,600)

TABLE 3-2. (Continued)

Year	Duesseldorf(2) Minimum Btu/lb. (kcal/kg)	Duesseldorf(2) Average Btu/lb. (kcal/kg)	Duesseldorf(2) Maximum Btu/lb. (kcal/kg)	Stockholm(3) Average Btu/lb. (kcal/kg)
1974	2,666 (1,481)	2,855 (1,586)	3,203 (1,779)	4,500 (2,500)
1975	2,954 (1,641)	3,145 (1,747)	3,374 (1,874)	4,410 (2,450)
Σ	11,334	34,570	13,118	34,623
N	4	13	4	8
Average	2,834 (1,574)	2,659 (1,477)	3,280 (1,822)	4,328(4) (2,404)

(1) Annual Averages of the Lower or Net Heating Value LHV in Btu/lb.

(2) Source: Operator of MVA Duesseldorf.

(3) Source: Vereinigte Kesselwerke A.G., Duesseldorf.

(4) Stockholm refuse reportedly contains a fairly high percentage of plastics.

(5) To convert from kcal/kg to KJ/kg multiply by 4.1868.

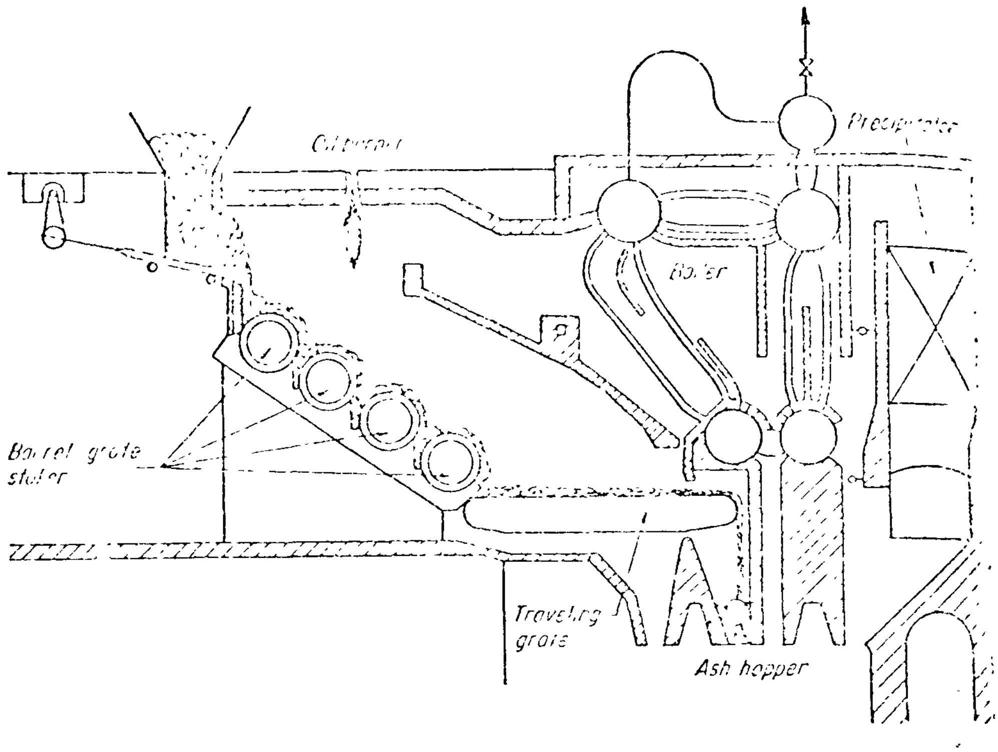


FIGURE 3-8. FIRST TEST INSTALLATION OF REFUSE ON BARREL GRATE ADDED TO EXISTING COAL-BURNING TRAVELING GRATE AT FLINGERN POWER PLANT

The sloping roof of furnaces No. 1 through 4 is in two parts as seen in Figure 3-9. The front roof is cooled by water tubes, as well as the longer rear roof. In these four furnaces, the total heating surface in each furnace is 100 m^2 (861 ft^2). The volume of Furnaces 1-4 was estimated to be 167 m^3 and in Furnace 5, 297 m^3.

First Open Boiler Pass, Units No. 1-4

With a furnace configuration as shown in Figure 3-9 it can be expected that burning is not complete as the gas flows upward out of the main furnace. This means that the ash particles carried in the burning gases are usually hot enough, over 982 C (1800 F), to be sticky. Accordingly, enough volume must be provided and that volume must be cooled for two reasons:

- Allow time for combustion to be completed, about 50 to 200 milliseconds
- Cool the gases so that deposits of ash particles will be dry and will be below the corrosive range.

Mr. K-H Thoemen, plant manager, has described the design of the first four boilers as follows:[2]

> "For different reasons, among others' economy, the construction and operation of large incinerator plants in Germany has been put into the hands of municipal power plants or similar institutions. This had the result that in the design of the incinerator plants, the same design elements have been used as in the design of coal-fired power plant steam boilers. For example, to save construction costs and volume, the incinerator steam generator was built directly on top of the furnace, instead of separating the furnace from the so-called waste heat boiler as practiced in former times. In addition, it was desired to utilize the steam for power generation and district heating. Therefore, the steam conditions were matched to those of the power plants.
>
> In 1967, after tube failures had been reported at other incinerator plants, in Dusseldorf the tubes just above the furnace were inspected and at the lower area of the side walls, the first indications of corrosion were found (Figure 3-9).

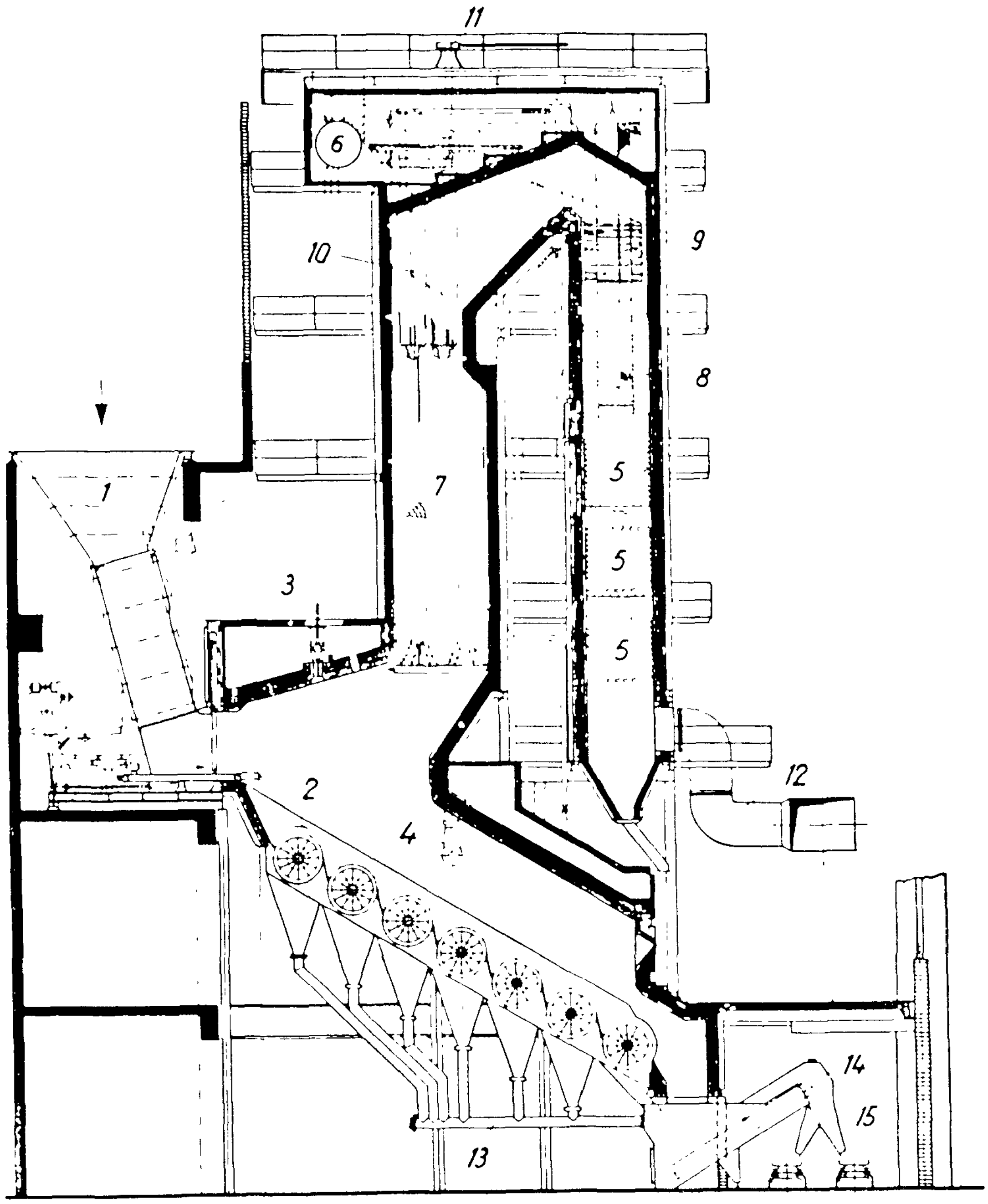


FIGURE 3-9. CROSS SECTION OF ONE OF BOILERS NO. 1-4 (COURTESY OF STADTREINUNGS UND FUHRAMT DUESSELDORF)

1. Refuse hopper
2. Refuse feeder and roller grate "system Duesseldorf"
3. Ignition burner
4. Oil burner (one side)
5. Economizer
6. Steam drum
7. Radiant water-tube-wall boiler
8. Boiler convection section
9. First and second stage superheater
10. High-temperature superheater
11. Steam discharge
12. Exhaust gas duct to electrostatic precipitator
13. Ash siftings removal
14. Wet residue conveyor
15. Residue removal to processing plant

As a means of protection, additional secondary air nozzles were installed to build up a curtain of excess air in front of the tubes. Furthermore, the endangered area was studded and covered with a 1/2-inch layer of silicon carbide refractory. In other plants, this method of protection already has been applied, with similar good results.

In 1968, a tube rupture occurred in one of our boilers. The cause was investigated and found to be corrosion by the flue gas. Subsequent extensive inspections of the boilers demonstrated that corrosion observed the year before had continued and reached the tube surface above the protected area (Location 3). Not only the side walls but now the front wall was affected. Ultrasonic measurements showed that it was necessary to renew about 30 to 40 tubes in each boiler for a length of about 7 feet. A considerable number of the remaining tubes had to be reinforced by welding. Moreover, an extended area of tube surface was studded and concealed."

In a futher endeavor to stop wall tube wastage in the lower part of the first boiler pass, more secondary air was added in the furnace roof and a refractory arch or "guiding wall" was evolved at the top of the furnace outlet (see Figure 3-10). Thoemen explains this evolution as follows:

"To guarantee a better burn-out and mixture of the flue gases in the existing units, the following changes were accomplished. The overfire secondary air was increased to about 25-30 percent of the total air. But the experience is, that with the overfire air by itself a complete mixture of the gases cannot be obtained. The relatively cold air does not blend with the gas but pushes it aside.

The first step to change the configuration of the furnace was done by the construction of a fire guiding wall. This is an arch-like wall of firebrick, built in at the end of the furnace front-roof. This guiding-wall hinders the direct flow of the gases along the roof into the first flue. Furthermore, it is a contraction of the profile of the furnace throat by which part of the gas with high excess air from the end of the grate is forced into the front part of the furnace. Because the secondary air nozzles are located directly in front of the wall, a better vortical intermixture of air and gas is achieved. The arch-like configuration of the wall contracts the gas flow in the center of the first flue which results in a more uniform directed gas stream.

The experience with this guiding-wall is very good. Since its erection in the years 1968 and 1969, tube corrosion in the first pass has not continued or spread out. Stream tests with a water-tank model and extensive gas analyses have proved the efficiency for the uniformity and burn-out of the gases."

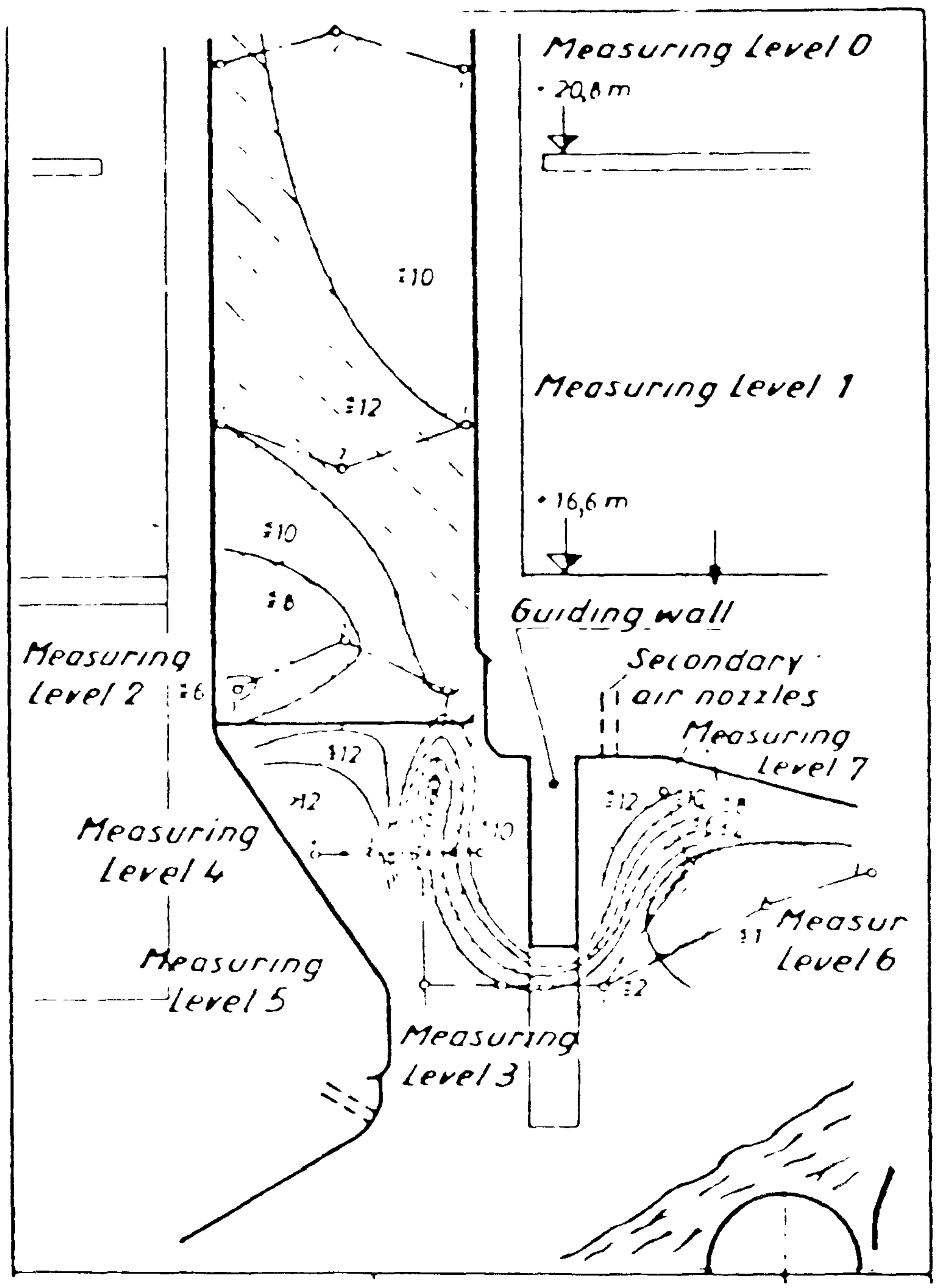


FIGURE 3-10. DIAGRAM OF LOCATION OF GUIDING WALL AT TOP OF FURNACE OUTLET SHOWING EFFECT ON OXYGEN DISTRIBUTION IN GASES

This guiding wall in Furnaces 1 through 4 was formed of high alumina content refractory and was not air cooled. Now these are made of silicon carbide. Because of the high temperature to which these refractories are subjected, they are now being air-cooled. Uncooled, their life was about 23,000 hours. The air cooling arrangement is discussed later under "Secondary Air". No. 4 was converted in early 1976, No. 3 in early 1977, and Nos. 1 and 2 will be converted to air cooling later (completed 1978).

Furnace Wall in Unit No. 5

The furnace for Unit No. 5, built in 1972, was altered in accordance with the experience gained in about 6 years' operation of Units 1-4. Also, the flow pattern in No. 5 was radically altered because of the rising heat value of Dusseldorf refuse. Instead of having the burning gases flow upward at an angle toward the furnace outlet as in Units 1-4, a sloping water-cooled baffle was built in No. 5 above the fuel bed as shown in Figure 3-11, in such a way that the gases first flow nearly parallel to the fuel bed, then at the end of the baffle, they turn and flow upward toward the furnace outlet. This provides a longer flame path and residence time for the hot gases resulting from the higher heat value of refuse.

One desirable achievement of this new design is that by the time the gases reach the top of the furnace and pass into the first pass, they are well mixed and cool enough to reduce corrosion. In late 1976, at the Engineering Foundation Conference at Hueston Woods, Ohio, Thoemen[3] stated regarding this new furnace in Boiler No. 5:

> "Although the tubes of the first pass have not at all been protected by ceramic lining, after more than 1 year of operation not any corrosion attack of the former kind was detected..." "The construction forms a true combustion chamber in the front part of the furnace. It is evident that in this combustion chamber, higher temperatures are generated than in the elder units; hence, the danger of slagging in the furnace had to be taken in to account... so that the furnace roof and the later fire-guiding wall were designed as steam generating water-walls, to carry off certain amounts of heat from the furnace.

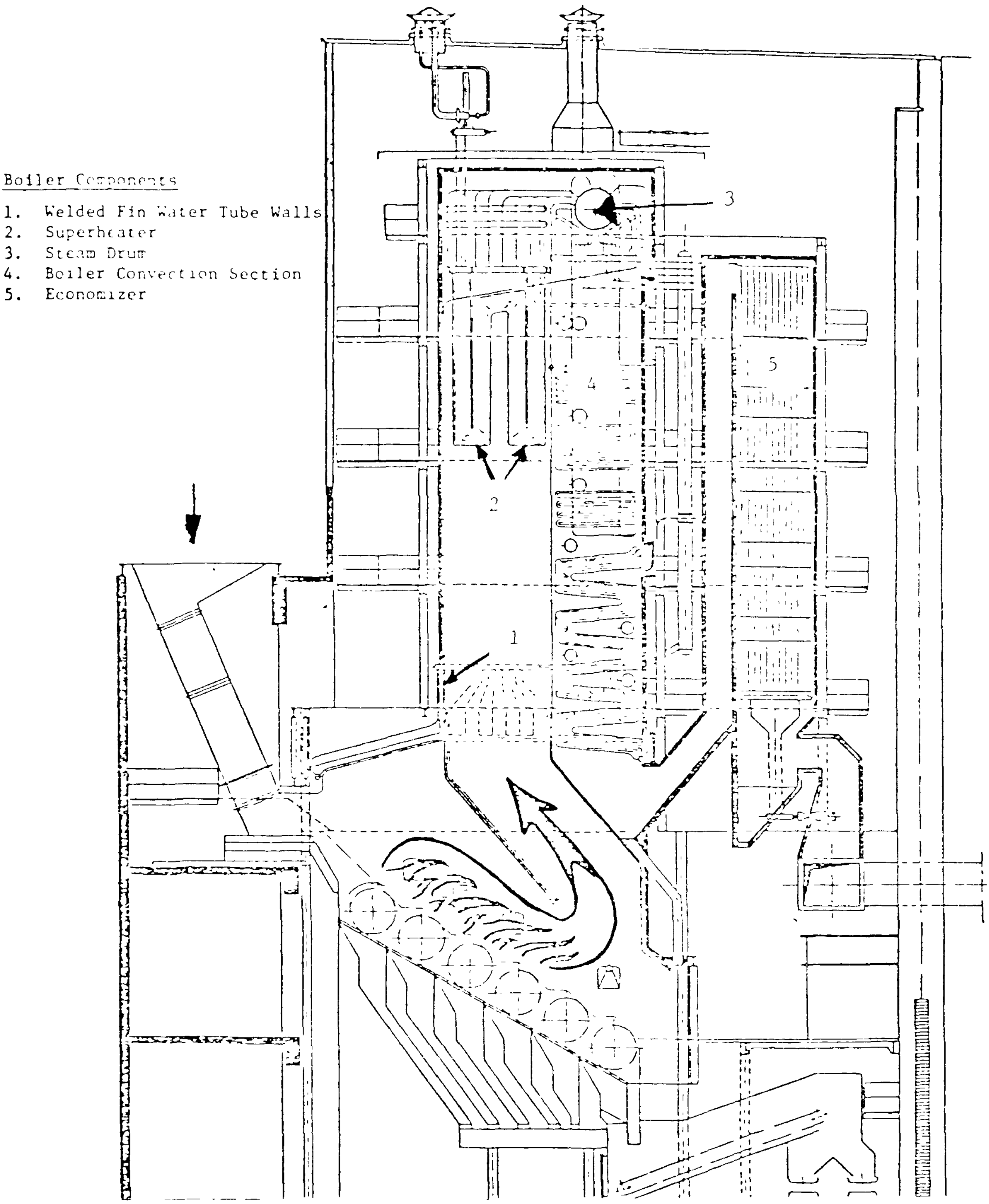


FIGURE 3-11. CROSS SECTION OF BOILER NO. 5 WITH ROLLER GRATE "SYSTEM DUESSELDORF" (Courtesy Stadtwerke Duesseldorf Kraftwerke)

For the sidewalls, the choice between water-walls and uncooled refractory lining was discussed. Water-walls would have solved the problem of slagging, but these tube surfaces need special care and maintenance. To protect them against corrosion and erosion, they must be covered with plastic refractory lining, which must be checked at frequent intervals, and if necessary, be amended. An uncooled lining of the sidewalls was chosen, under consideration that the ignition of refuse with low heating values must be supported. The refractory material, which is most suited is SiC (silicon carbide) on account of its slag repellent property. On the other hand, it is known that the use of SiC materials in furnaces is problematic, when temperatures of 900 C (1650 F) to 1010 C (1850 F) exist and the flue gas contains considerable amounts of O_2 and H_2O. Experience of American operators communicated to the manufacturers of the refractory materials in Germany had indicated unsatisfactory performance. Accordingly, after 6,000 operating hours, the SiC lining of the front part of the furnace was totally damaged. The furnace had to be reconstructed with plastic refractory on an AL_2O_3 base. Now the slagging problem appeared again, and during the following operation period several times heavy slag formation occurred at the side walls, which made it necessary to shut the boiler down and remove the slag. In order to achieve a further undisturbed operation, the combustion was shifted to the end of the grate. Instead of air, recycled flue gas was injected under the first roll of the grate. Due to the oxygen reduction in the forward combustion chamber, the main combustion zone moved one roll downward along the grate. Consequently, the burnout time for the flue gas was shortened, and after an operation time of about 1 year, the first corrosion on the tube surfaces of the front wall of the first pass occurred.

Because of the unsolved problems with the furnace, the endangered area, about 2 m (6.5 ft) in height, was studded and lined with plastic refractory. Later no further corrosion was found in this zone.

In 1974, a new composition of SiC material was offered by "CARBORUNDUM", a manufacturer of refractory, which was supposed to withstand the forementioned attacks. Two test areas of this material were incorporated at the zone with the highest heat load. After 11,000 hours of operation, it can be said that this material promised to give sufficient life and to have satisfactory slag repellent capacity.

No further damage of the first furnace lining occurred. Only a minor attack and waste of the brick surface was observed. Resting upon this experience, the lower halves of the sidewalls were rebuilt with the previously mentioned SiC bricks.

> Moreover, this part of the lining is air cooled by the use of hollow bricks. The secondary air is employed as cooling medium and is then finally injected into the furnace through three horizontal groups of sidewall nozzles. Similar designs are known in American plants."

Wall Construction in Unit No. 5

While the walls in Units 1-4 were either refractory or spaced water tubes backed by high-temperature insulation, the non-refractory water-tube walls in Unit No. 5 are "membrane walls"; that is, each tube has two welded fins, 10 to 12 mm (0.4 to 0.5 in) facing the adjacent tubes. The joint between the fins is also welded forming a solid, water-cooled membrane wall.

Wall Protection

When the first plastic-refractory coating was applied to water-tube walls at Dusseldorf, the 10 mm (0.4 in) diameter studs were welded to the wall tubes at a density of 2,800 per m^2 (260 per ft^2). Later this density was reduced to 2,200 (204).

To cover the studs, a moldable form of silicon carbide is preferred if an accumulation of slag is expected because SiC tends to repel the adherence of sticky slag. Where slag is little problem, a plastic refractory such as Plibrico, 75 mm (2.9 in) thick is used.

Superheater

In all boilers at this plant, the high-temperature section of superheater is a suspended platen type located at the top of the first open boiler pass as shown in Figures 3-9 and 3-10. Experience at many plants has indicated that it would be desirable to position the superheater at a greater distance from the main furnace. For one thing, the gas cooling rate is relatively slow as it rises in the first open pass toward the superheater. Thus, if there are frequent bursts of high temperature gas leaving the furnace because of the inhomogeneity of the refuse causing erratic burning, there are then likely to be moments of excessive gas temperature striking the exposed bends of the suspended platens. Also, in the case of Units No. 1-4, there is direct radiation from the furnace to the platens which may contribute to overheating any ash deposits on the platens.

The rest of the superheater sections in this plant are horizontal type at the top of the second pass. Thus, the flow of steam through the superheater sections is counter flow, with the steam first meeting partially cooled gases as they pass through the horizontal sections in the second pass. Then the partially superheated steam flows to the suspended platen section in the first pass where it meets hotter gas in a range of 700-800 C (1292-1472 F).

The superheater for Units No. 1-4 is made up of three sections having the following heating surface: 83, 91, 52 m^2 (893, 929, 560 ft^2). The superheater for No. 5 is in two sections. Material in these five units and dimensions are as follows:

Units 1-4	Unit 5	
	First Section	Second Section
Carbon: 0.12 - 0.20	0.1 - 0.18	<0.15
Silicon: 0.15 - 0.35	0.15 - 0.35	0.15 - 0.5
Manganese: 0.5 - 0.7	0.4 - 0.7	0.4 - 0.6
Phosphorus: <0.04	<0.04	<0.04
Molybdenum: 0.25 - 0.35	0.4 - 0.5	0.9 - 1.1
Chromium: None	0.7 - 1.0	2.0 - 2.5
Tube Diameter: 33.7 mm (1.33 in)	38 mm (1.5 in)	
38 mm (1.5 in)	38 mm (1.5 in)	
31.8 mm (1.25 in)	44.5 mm (1.75 in)	
	31.8 mm (1.25 in)	
Tube Spacing: 150 mm (5.9 in)		
150 mm (5.9 in)		
600 mm (23.6 in)		

Experiences with Superheater Corrosion

Thoemen has recently published[3] a review of corrosion:

"In the time from 1970 to 1972, fireside qorrosions of a considerable rate appeared on the final state platen superheaters on Boilers No. 1-4, which are installed at the upper end of the first flue. The tube side, being directed against the gas flow, showed a rapid material wastage at a rate up to $4,5 \times 10^{-6}$ m/h (0.00018 in/hr). At first, this corrosion was interpreted as chlorine corrosion under lack of oxygen. Gas analyses, however, showed, that in these parts of the boiler, sufficient oxygen is present at any time. Only extensive analyses of the deposits of the tubes have shown a chlorine-corrosion released by the transformation of alkalichlorides into sulphates within the deposits. As a partial remedy, the endangered tube parts were provided with protective shields in form of flat steel. This proved to be sufficient, but as these steel bars are cooled insufficiently, an inspection and eventually a partial renewal has to be made at every shut-down of the boiler, approximately every 3 months. To cut down the maintenance costs, another tube material was sought for better resistance against this corrosion. This is an austenitic steel which has the German standard specification:

X8CrNi Nb 1613,

Its composition is:

C = (equal or smaller than) 0,08 %
Si = 0,25 - 0,55%
Mn = 1,10 - 1,4%
Cr = 15 - 17%
Ni = 12 - 14%
Nb = (more than) 10 times C

In 1972, platens of this material were installed. On occasion of a boiler inspection, after 16,000 hr, no substantial material wastage could be found. But lately (1976), the first failure of these platen tubes happened. The loss of material is strictly limited to the outside surface of the 90° bend of the U-shaped tube. The horizontal and vertical parts of the tubes are completely unharmed. By the appearance of this damage, it can perhaps be concluded that by bending the tubes not only a reduction of the thickness of the outer wall occurs, but a structural change of the material occurs too, which makes it sensitive to corrosion. Tests about this matter are running, but not yet concluded, so that final statements cannot be made. In relation to the corrosion rate of 1970, these tubes have been a significant improvement, although no protective shields have been used on these tubes.

Returning to the boiler which is in service since 1972, No. 5, it must be said, that similar good experience with this unit has not been achieved. Contrary to the anticipated effect of a reduced suspectibility for corrosion, considerable difficulty arose with this new unit too. There occurred corrosion phenomena of kinds not known before.

Although the corrosions of the wall tubes of the first boiler pass in No. 5 are under control, a totally different picture is presented in the superheater area. Both the final stage superheater and the convection superheater were affected by numerous attacks and damages since startup. The tube failures of the superheaters have been as follows:

- 22 failures of convection superheater tubes (see No. 2 of Figure 3-11)
- 13 failures of final superheater tubes (see No. 3 of Figure 3-11).

An accumulation of that kind of tube failures caused by corrosions has not been observed in former years. The final (suspended platen) superheater which is of nearly the same design and arrangement as in Boilers No. 1-4, had to be renewed in two steps in the years 1973 and 1974. The cause of this failure was a fault in the design. The 14 tubes of each platen superheater had been welded together instead of being clamped. Hereby the tubes were hindered in their expansion so that after a short operation period, they were completely twisted and no longer hung vertical at the leading edge of the tubes, not only the outward tubes were endangered, but the superheater platens presented larger surfaces to the corrosion attack. With the renewal of the first half of this superheater, the first four outer tubes of each platen were made of the same austenitic steel mentioned earlier. But after about 6,000 hours of operation, one of these tubes failed and the others showed considerable attack too. Investigations were made in order to trace the cause of this short tube life, compared to that of the same tubes in the other boilers. A new phenomenon was found not known up to that date. On the presuperheater too, being located at the upper end of the second gas pass as a convection tube bundle, corrosion occurred to an extent not known from the other boilers. Not only the tube bends were affected, but at the middle section of the tube bends, the material was carried away at the top side, the material loss at the middle sections occurred at both sides of the tubes at an angle of about 30° to the vertical axis as a longfaced erosion. In addition, not only the first or second row of the tubes is affected, but the damages continued throughout the whole upper tube bundle."

Causes of the Corrosion

"By search for the possible reasons of this intensified corrosion, it was found that in 1973 about 1 year after the start of operation of Boiler No. 5 a new situation had come up in the method of operation. In May, 1973, a shredder-installation for bulky refuse (wood of any kind, furniture, boxes, crates, etc.) was started.

> Due to space arrangements between the shredder and the boiler, most of the shredded material is fed into this unit."

Mr. Thoemen believes this is caused by a concentration of potassium chloride in the tube deposits.

Thoemen's conclusions regarding corrosion protection for superheaters is:

- Good mixing of refuse to avoid concentration of corrosive salts in one boiler
- Clamp protective metallic shields on tubes at vulnerable locations. He finds that a convenient alloy for this purpose(similar to 1.0% Mn) Sicromal 8 plus because it can be formed and welded is:
  - Carbon: 0.1%
  - Silicon: 1.0%
  - Aluminum: 0.8%
  - Manganese: 1.0%
  - Chromium: 6.5%.

  The shield lasts 3 to 12 months.
- Use alloy steels in tubes
- Plasma-gun coating by metallic or ceramic materials. This will be tried at Duesseldorf.

Figure 3-11a shows a hard coating applied in 1977 on bends of superheater tubes to be installed in the second pass of Boiler No. 5 to determine its usefulness in reducing tube wastage.

Soon after Boilers No. 1-4 began operation in 1965, a limited amount of corrosion appeared in the top tube row of the horizontal superheater sections in the second pass. However, as soon as a protective deposit developed there, corrosion almost ceased. Thoemen described this situation in 1972[(2)]:

> "For the first time after about 1,000 hours of operation time, we experienced comparatively severe corrosion on the tubes of the first stage superheater at the side of the direction of gas flow. The uppermost rows of tubes of the superheater carried, under a relatively small scale of deposits, a heavy layer of corrosion products. By the thickness of this layer, it had to be concluded that rapid wastage of these tubes could be expected. However, as operations continued, the corrosion rate declined and has reached a level which causes a barely measurable waste of material. The tubes now are covered with a hard layer of deposits."

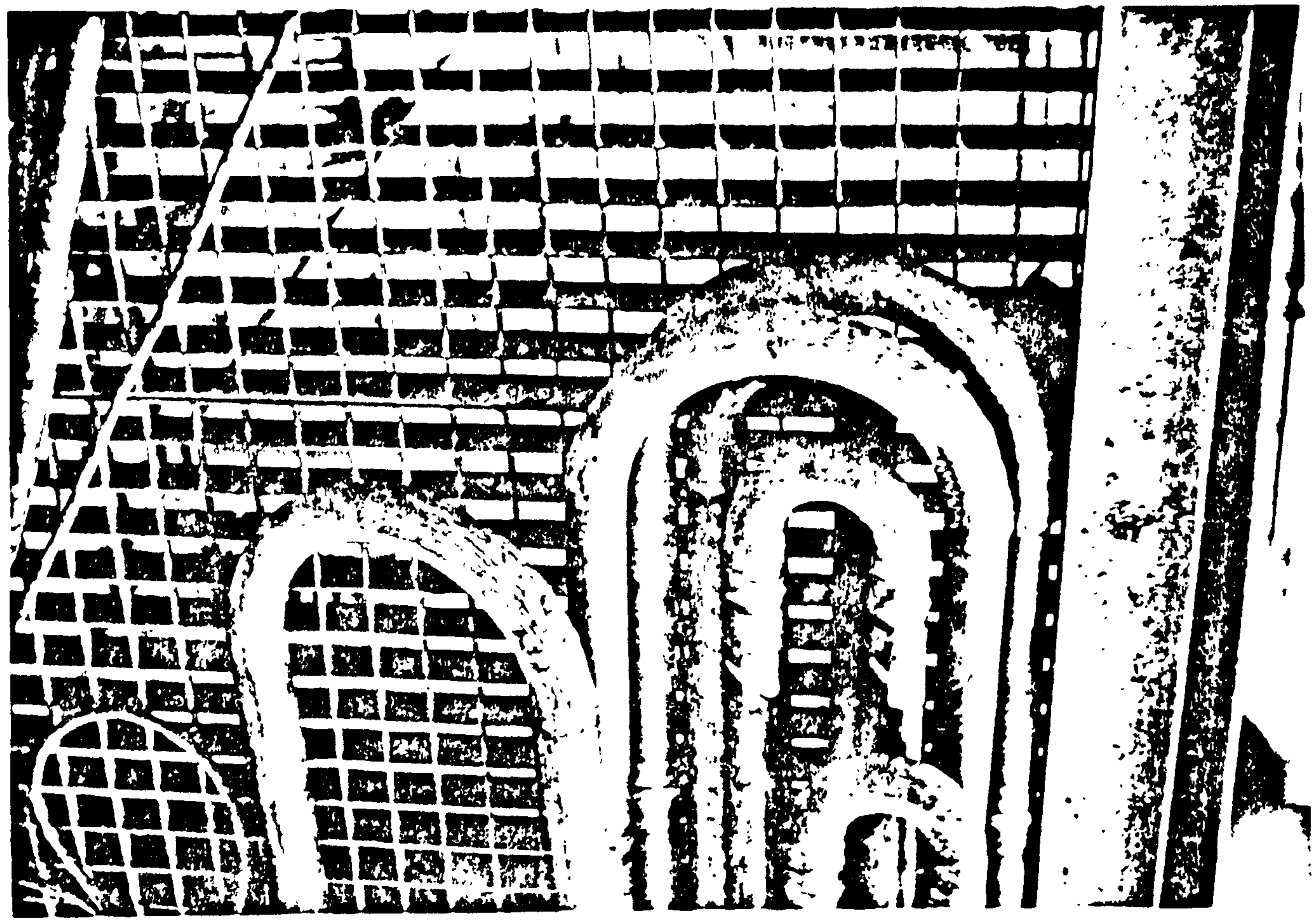


FIGURE 3-11a. HARD COATING ON BENDS OF SUPERHEATER TUBES TO BE INSTALLED IN THE SECOND PASS OF BOILER NO. 5 (Photographed on May 17, 1977)

The importance of a protective deposit is thus emphasized. Also the deleterious effect of any action, such as excessive soot blowing, is emphasized. However, at this plant, excessive tube wastage because of soot blowing has not occurred. Mr. Thoemen emphasized the importance of the following in safe soot blowing:

- Steam lines must be well drained to avoid blasting slugs of water against the tubes. Tubes are blown once per shift.
- Protective shields are very successfully used to guard against soot blower erosion.
- Steam jet pressure must not be too high.
- A thermocouple in the steam line can be used as an operating guide. The temperature should be well above saturation temperature to avoid blowing slugs of water when the soot blower is turned on.

Boiler (Convection Section)

The convection section of the boiler is located in the lower portion of the second pass as seen in Figure 3-9. Some erosion by fly ash has been experienced in this area. In Boilers No. 1-4, this occurred only at the outside of the first row of tubes where the gas flow pattern caused a concentrated stream of fly ash to impinge against the metal. In Boiler No. 5, after 28,000 hours, steel cladding was added to shield these tubes against erosion.

The boilers in No. 1 and No. 2 were built by Duerr. Those in Nos. 3 and 4 were built by Vereinigte Kesselwerke. No. 5 was built in joint responsibility of both firms. Both companies are now a part of Deutsche Babcock. No. 1-4 are rated at 20 t/hr. No. 5 is rated at 30 t/hr.

The entire boiler is water cleaned in Units No. 1-4 every 2,000 hours. No. 5 is similarly cleaned every 5,000 hours. At first, the tubes are sprayed for 10-12 hours at the rate of 10 m^3/hr (44.0 gpm) to soak the deposits. Then the weakened deposits are removed the next morning by means of a high pressure water jet.

Economizer

The plain tubular economizer generates about 5 percent of the steam produced in each unit. The gas temperature entering is 525 C (980 F) and leaving is 237 C (459 F). Excessive soot blower operation in the economizer has caused some tube failure.

Boiler Water Treatment

Because this plant feeds its output of high-pressure, high-temperature steam to the turbines at the nearby Flingern power plant, it receives all of its feedwater from that plant. It is fully demineralized and deoxidized.

Primary Air Supply

The primary air to each of the five boilers is supplied by one axial flow fan built by Buttner-Schilde-Haas. For Boilers No. 1-4, the maximum volume is 11 m^3/sec at 110 C (23,304 cfm at 230 F) at 180 mm (7 in) water. The preheated air is heated by means of heat exchangers heated by condensate returning from the Flingern Power Plant 600 m (1,970 ft) away. For Boiler No. 5, the primary air rate is 52,800 Nm^3/hr (14.67 Nm^3/sec or 31,080 cfm) at a pressure of 240 mm (9.5 in) water.

The air flow to each of the seven grate rolls in Boilers No. 1-4 is controlled by a separate damper which is adjustable manually. The vane position of the fan is controlled automatically from excess air as measured approximately 1 to 2 m (3.3 to 6.5 ft) up into the first pass above the furnace. An effort is made to control the O_2 at that point to between 6 and 8 percent. A similar system controls the air to the six rolls in Boiler No. 5.

A membrane type manometer connected to each grate roll zone provides an indication in place. The condition of the main and secondary air flow is indicated in the control room. The total primary and secondary air flow to each boiler is measured by means of a venturi.

As already indicated, there is no redundancy in the air supply to each boiler but performance for 12 years has been excellent. However, the zone control dampers require lubrication and have a tendency to bind.

Secondary Air

This plant provides an interesting view of the evolution in the application of overfire air to maintain complete combustion. Apparently the experience with the first small pilot furnace from 1961 to 1965 led the designers of Boilers No. 1-4 to specify only a nominal secondary air flow per boiler of 4,000 Nm^3/hr (2,354 scfm) at a moderate pressure of 280 mm (11 in) water. This air was supplied to a total of 44 nozzles in each boiler distributed as follows:

- 18 pointing nearly downward in the water-cooled front roof
- 20 pointing at an angle down and forward in the water-cooled rear roof
- Six in each refractory sidewall.

As had already been discussed under the topic "First Open Boiler Pass", in 1967 an inspection of the water-tube walls in the first open boiler pass immediately above the furnace revealed tube wastage in the front wall (Figure 3-9) which appeared to be caused by the flow against these tubes of high-temperature flame having low oxygen content. To obtain a higher oxygen content at that point, the number of secondary air nozzles was increased. Also, the secondary air pressure was increased from 280 mm (11 in) water to 500 mm (23.6 in) water and the available air volume was increased from 4,000 Nm^3/hr (2,354 scfm) to 10,172 Nm^3/hr (5,988 scfm).

In addition, in 1976, more secondary air was introduced in Boilers No. 1-4 through the air cooled refractory arch or guiding wall which has been described earlier. The air cooling system for this silicon carbide arch has now been evolved to contain 62 air holes in two rows of 31 each. Sixteen of the holes are 30 mm (1.2 in) diameter and 46 of them are 60 mm (2.4 in) diameter. The secondary air flowing into the furnace through this arch cooling system becomes heated to about 300 C (572 F).

Boiler No. 5 has a larger secondary air supply: 15,000 Nm^3/hr (8,828 cfm); and a considerably higher air pressure: 800 mm (31.5 in) water. In addition to nozzles in the front and rear roof similar to Boilers No. 1-4, there are three rows of six sidewall nozzles each, the lowest row about 1.5 m (4.9 ft) above and parallel to the sloping grate line.

These overfire air systems have operated satisfactorily except that at first there was insufficient air supply. In the air piping systems, the individual nozzles have been connected to the air manifolds by flexible steel hoses. Because of overheating of some of these connections, they are being converted to stainless steel hoses.

Co-Firing Equipment

The only auxiliary fuel used at this plant is No. 2 fuel oil which is used only for start-up or in an emergency. There is a legal requirement on incinerators that the combustion gases must attain a level of 800 C (1,472 F). If there is very wet refuse or some other cause for the furnace temperature to fall below that limit, the oil burners can be used to raise the temperature. Originally, Boilers No. 1-4 had three oil burners at the top-front-center of the furnace between the feed chute and the arch. Now there is only one burner per unit. The burner for No. 5 is on one side. Maximum oil capacity per burner is 0.4 tonnes/hr (130 gal/hr).

Heat Release Rate

The following approximate heat release rates have been estimated based on the grate areas and furnace volumes calculated from dimensions scaled from available diagrams. The combustion volume in Furnaces No. 1-4 was taken as 167 m^3 (5,285 ft^3) and for No. 5 was 297 m^3 (10,487 ft^3). The corresponding grate burning areas were taken as 49.71 m^2 (527 ft^2) and 42.63 m^2 (458 ft^2), respectively. The lower heat value was assumed to be 1,850 kcal/kg (7,746 KJ/kg or 3,330 Btu/lb).

	Boilers No. 1-4	Boiler No. 5
Burning Rate, per boiler, tonnes/day	240	300
Burning Rate, per boiler, tons/day	264	330
Burning Rate, on grate, kg/m^2-hr	201.4	293.2
Burning Rate, on grate, lb/ft^2-hr	41.17	60.0
Burning Rate, on grate, $Kcal/m^2$-hr	372,220	542,420
Burning Rate, on grate, MJ/m^2-hr	1,558	2,271
Burning Rate, on grate, Btu/ft^2-hr	137,350	200,155
Heat Release Rate, $Kcal/m^3$-hr	110,778	77,862
Heat Release Rate, MJ/m^3-hr	464	326
Heat Release Rate, Btu/ft^3-hr	12,449	8,750

The inclusion of a portion of the first pass as active furnace volume may increase that volume by 21 percent in the case of Furnaces No. 1-4 and 18 percent for Furnace No. 5. Thus, the above volume heat release rates would be 18 to 21 percent higher if the burning were considered to be entirely contained in the main furnace.

The above burning rates and heat release rates are conservatively low, especially for the relatively low heating value refuse obtained in Duesseldorf.

Energy Utilization Equipment

Because this refuse to energy plant was built adjacent to and connected to the Flingern power plant, the entire output from the burning of refuse goes 700 m (2,300 ft) to the turbines at the Flingern plant in the form of high pressure, 80 bar (1,500 psig or 104 atm) high temperature steam, 500 C (932 F). Here it is utilized in two double shaft condensing steam turbines, two high perssure generating about 32 mw and 11 mw and 2 low pressure generating about 53 and 30 mw. Steam extracted from the 50 mw turbine is used to produce hot water at a maximum of 130 C (266 F) for district heating. Early this year (1977), the Federal government issued regulations permitting 180 C (356 F).

In the summer, the refuse-burning plant supplies practically all of the energy needed for district heating. On such days with an outdoor temperature of 20 C (68 F), the district supply water temperature is 80 C (176 F) and the system return temperature is 65 C (149 F). The system water flow rate is then 800 m^3/hr (3,520 gpm). In the winter at an outdoor temperature of -10 C (14 F), the flow rate is 1,400 m^3/hr (6,160 gpm) at supply and return temperatures of 130 C (266 F) and 70 C (158 F).

The district heating loop is 15.9 km (10 mi) long and serves 133 buildings included in which are 8,000 apartments. The peak heat demand is 110 Gcal/hr (460.6 GJ/hr or 27.72 MBtu/hr). For comparison, the maximum rated output of the five boilers at the refuse burning plant is 110 tonnes/hr (121 tons/hr), equivalent to approximately 88.5 Gcal/hr (371.7 GJ/hr or 22.3 M Btu/hr). However, this full capacity, 963,600 tonnes per year, is never available all at one time.

In 1975, this plant burned 297,359 tonnes of refuse (327,095 tons) and delivered 560,002 tonnes (617,570 tons) of steam (1.89 ton/ton) to the Flingern Power Plant, which is 58.1 percent of full rated capacity. The income from this output was 8,125,629.02 DM ($3,412,764.20) a rate of 14.5 DM/tonne ($5.53/ton) or $2.76/1,000 lb (approximately $2.76/$10^6$ Btu). In addition, some steam is used internally for turbine-driven feedwater and condenser cooling water pumps.

<u>Plant Start-Up Procedure</u>

The following start-up procedure as described by Mr. Thoemen is used:

- Check all access ports, assure that all workers are outside, that internal equipment appears in order. This check takes 1 hour.
- Fill the boiler with feedwater. Preheat the boiler with steam from the intermediate pressure line and build the pressure to 20 atm (275 psig). This takes 4 to 8 hours.

- Adjust the steam flow to blow out any condensate from superheater and set valve about 40 percent open.
- Start primary air fan at minimum flow, start grate rollers and start hot condensate flow through air preheater.
- Over the next 45 minutes, complete the following:
  - Fill refuse feedchute
  - Start refuse feeder
  - Cover first two rollers with refuse
  - Light oil burner
  - Increase feed gradually at rate governed by rate of rise of superheat temperature and drum pressure
  - Start flow of steam to Flingern Power Plant.

The total elapsed time for this start-up procedure is usually 8 to 10 hours.

Shut Down

- Crane stops filling chute.
- Empty chute onto grate over a period of 2 to 3 hours.
- Increase furnace draft to maximum.
- Reduce primary air.
- Complete burnout of refuse on bed over a period of 1 to 1-1/2 hours.
- Stop steam flow to main line.
- Vent steam to intermediate line.
- Continue primary air fan for 4 to 6 hours.
- Turn off fans to allow final cooling by natural draft.
- After 24 hours, begin repair work on unit.

Emergency Shut Down

- If a tube fails, shut off steam flow to main line.
- Shut off primary and secondary air.
- Extinguish fire with fire hoses.
  - Complete extinguishment takes 5 to 6 hours.
- Turn grate off.
- Stop feedwater pumps.
- Empty grate.

POLLUTION CONTROL EQUIPMENT

The four original boilers were equipped with two Lurgi Electrostatic Precipitators having a design efficiency of 99+ percent. In each precipitator, the gas flow is divided into 28 passages, each 0.226 m (8.5 in) wide. The height of the passage is 6.27 m (20.6 ft) and its flow length is 5.75 m (18.9 ft). Total projected collection area in each precipitator is 2020 m^2 (20,800 ft^2). The inlet flow area is 37.6 m^2 (406 ft^2) and the design velocity is 1.1 m/s (3.7 ft/s). Design flow rate was 39,000 Nm^3/hr (22,952 scfm).

Table 3-3 by Konopka[4] gives the results of two precipitator tests at this plant in 1967 by the government testing organization, Technische Uberwachungs Verein Rheinland, e.v. (TUV). The report indicated that in one test, the combustible content of the collected dust was 6.6 percent and its resistivity at 220 C (432 F) was 6 x 10^7 ohm-cm. Konopka recorded similar measurements by TUV at other plants that gave similar values.

Boilers No. 3 and 4 are served by an identical precipitator to that serving Nos. 1 and 2. Boiler No. 5 is served by a third precipitator. All three precipitators are connected by a manifold to a single chimney. By means of multi-vane butterfly dampers, the flow from any boilers can be fed to either of the three precipitators. The damper blades are 574 mm (22 in) wide and are shaped to present a "knife edge" to upstream and downstream flow when open. This shape helps to minimize deposition of ash on the blades. The upstream edge of each blade is made of manganese steel. To further discourage deposition and erosion, each blade is shielded upstream by a manganese steel I-bar positioned 20 mm (0.79 in) upstream. The damper assembly was made by Warmekraft-Gesellschaft Stobert Morlock of Recklinghausen, Germany.

The installation of precipitator No. 3 for Boiler No. 5 by Rothemühle in 1972 was preceded by a flow model study although the approaching flow pattern produced by the flue gas manifold was not modeled. It has two fields and 30 rows of collector plates spaced 300 mm (11.8 in) apart. The plates are 10 m (32.8 ft) high and each field is 3 m (9.8 ft) long. Effective projected collector surface is 3,600 m^2 (38,730 ft^2). Perforated distributor

TABLE 3-3. RESULTS OF TWO PERFORMANCE TESTS BY TUV ON A PRECIPITATOR AT THE DUESSELDORF REFUSE PLANT

Test Number	1	2
Firing Mode	Refuse	Refuse
Rated Gas Volumes M^3/S °C	44.00 260	44.00 260
FT^3/S °F (V Design)	15502 500	15500 500
Actual Gas Volume M^3/S °C (Measured at Pptr. Outlet)	43.00 235	43.50 242
FT^3/S °F (V Actual)	15205 455	15350 460
1000 ACFM °F (4)	91.0 455	92.0 405
Percent of Rating (Percent)	97.7	98.9
Actual (Test) Pptr. Inlet Dust Conc. (gm/Nm^3)	11.0	13.1
(gr/SCF)	4.31	5.69
Actual (Test) Pptr. Outlet Dust Conc. (gm/Nm^3)	0.036	0.042
(gr/SCF)	0.0158	0.0184
Guarantee Collection Efficiency (Corrected for Actual Test Conditions per Manufacturer's Corrosion Factors (Percent)	98.35	98.95
Actual (Test Collection Efficiency) (Percent)	99.67	99.68
Pptr. Design Gas Velocity at Rated Volume (in/sec)	1.16	1.16
(ft/sec)	3.82	3.82
Pptr. Actual (Test) Gas Velocity (v) (in/sec)	1.14	1.15
(ft/sec)	3.74	3.77
Design Migration Velocity (ft/sec)	.408	.319
Actual Migration Velocity (ft/sec)	.399	.406
Pptr. Electrical Energization Data		
Secondary Kilovolts Inlet (KV) (Inlet/Outlet)	31.5/29	31/29
Secondary Mill-amps (MA) (Inlet/Outlet)	265/267	313/310
Input Power (AXB) (Kilowatts) (Inlet/Outlet)	8.3/7.7	9.7/9.0
Power Density-Watts per 1000 ACFM (Inlet/Outlet)	91.7/85	105/97.7
Power Density-Watts per Ft^2 C.E. (Inlet/Outlet)	.401/.372	.466/.432
Field Strength-Kilovolts per Inch (Inlet/Outlet)	0.74/0.68	0.73/0.68

Note: No = corrected to 0°C and 760 mm Hg; 0.0736 mm Hg. water vapor pressure. pressure.

plates produce an excellent velocity flow distribution entering the first field at an average velocity of 0.834 m/s (2.74 f/s). Residence time is 7.2 seconds.

A power supply of 95.5 KVA is available to each field at 55 KV. No-flow voltage is 78 KV. Normal current is 600 ma, maximum 900 ma. Power consumption per field is 33 Kw.

Rapping is by means of gravity hammers operated automatically in a prescribed sequence. Unlike many outdoor precipitators, these hoppers are not heated. They are covered with 100 mm (3.9 in) of insulation. There is no problem of condensation causing sticking of the ash in the hoppers because there is no storage of fly ash there.

Originally, the ash removal system was pneumatic but this was abandoned after 2 years and was replaced by screws. Some modification of the fitting of the screws to the hoppers was needed to facilitate ash removal.

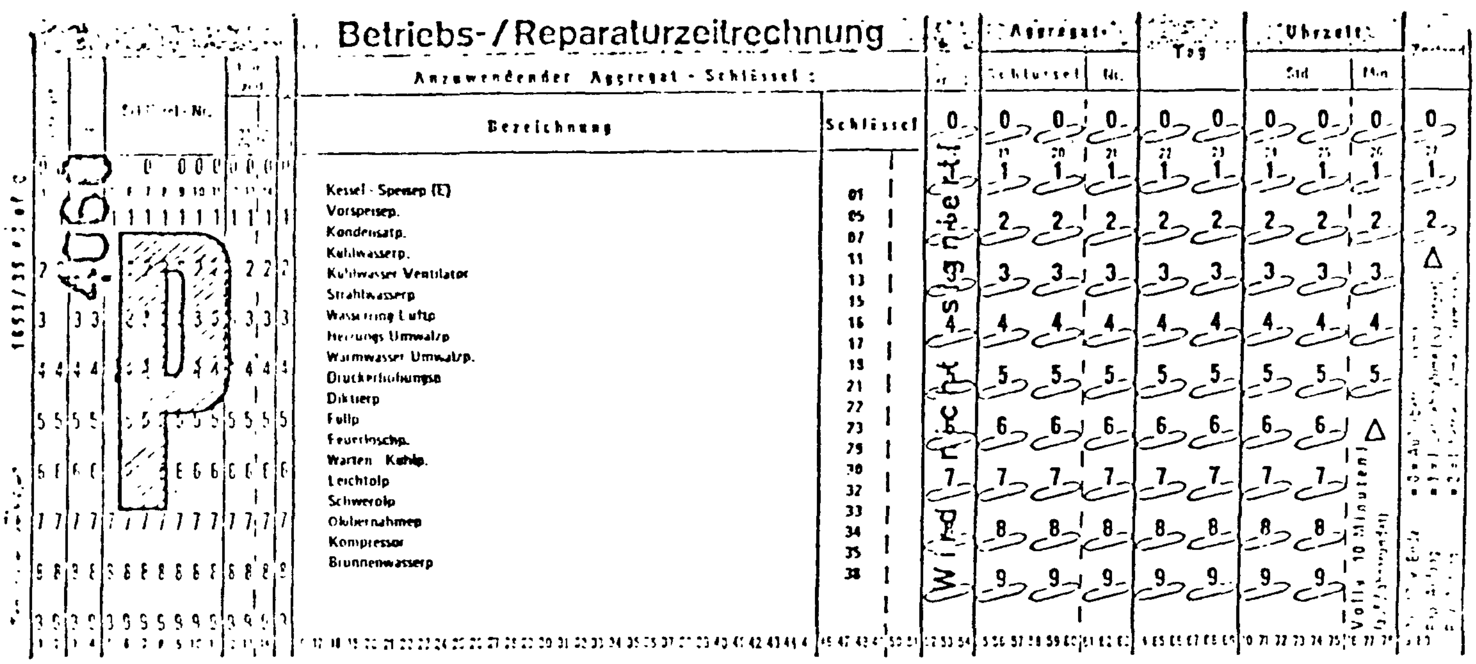
One 24-hour test by TUV showed the particulate emission rate to range from 80 to 100 mg/Nm^3 corrected to 11 percent CO_2 (0.0352 to 0.044 grains/ft^3).

The applied voltage on the precipitators must be continuously recorded as required by the county licensing board. The record must be stored for 5 years.

The availability for service of the individual precipitators is shown by the record for the last 2 years:

	Availability, Percent	
	1975	1976
Precipitator No. 1	99.3	99.2
Precipitator No. 2	99.6	100.0
Precipitator No. 3	100.0	92.7

Figure 3-12 is an example of two of the operation and maintenance computer cards which are used at the plant to maintain systematic records on the precipitators and other components.



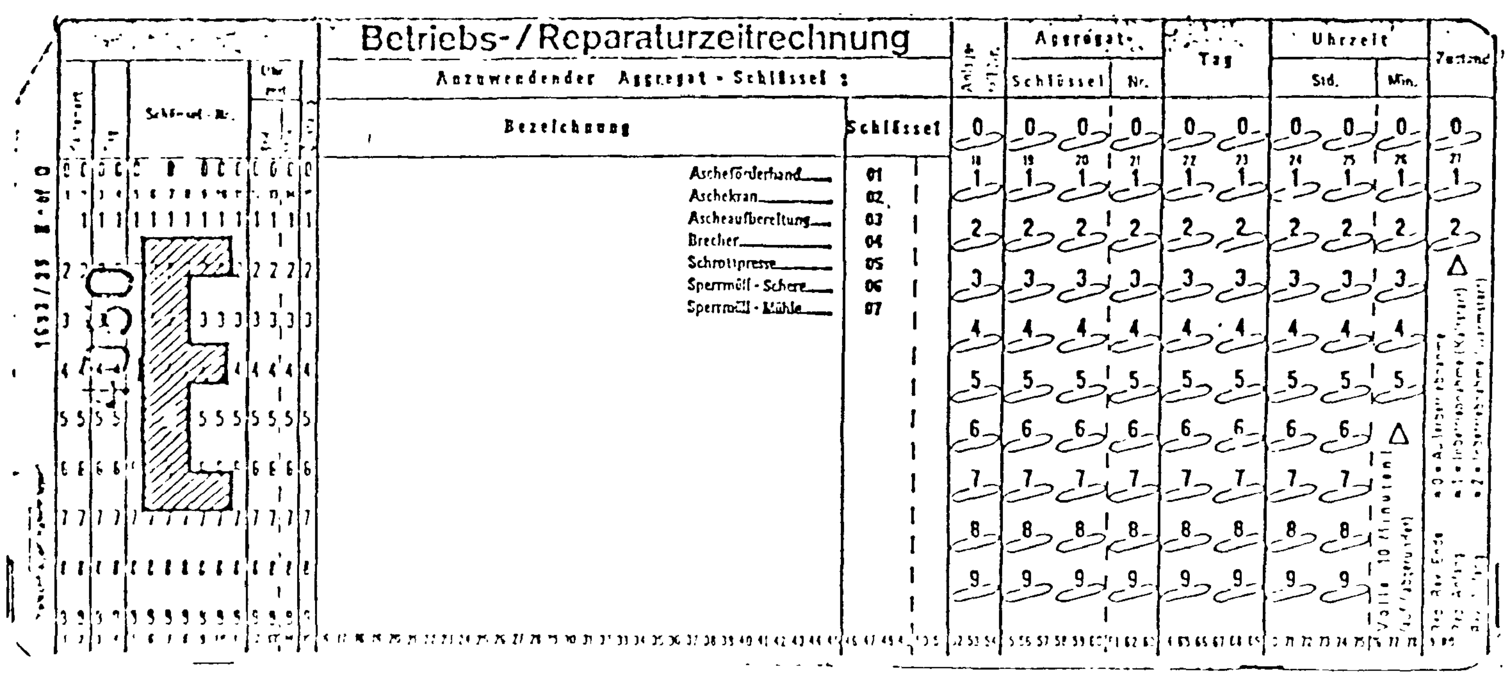


FIGURE 3-12. SAMPLE DATA CARDS AS USED IN PLANT DATA SYSTEM AT DUESSELDORF

Wastewater Discharge

Wastewater from boiler blowdown and ash disposal go to a settling tank and then to the city combined sewer system.

Stack Construction

The chimney 100 m tall (328 ft) is 80 m concrete and 20 m bricks, with a firebrick lining surrounded by 150 mm (5.9 in) foamed glass insulation. In 1971 after 6 years service, some of this insulation had to be replaced.

EQUIPMENT PERFORMANCE ASSESSMENT

The product of this plant is high-pressure, high-temperature steam. In 1975 it delivered 58.1 percent of its rated steaming capacity. Actually since the plant design philosophy is to have one boiler always in reserve this output was nearer to 70 percent of nominal operational capacity. Considering the inherent difficulty involved in handling wastes as fuel with all these problems the neat and well-maintained appearance of this plant and its grounds, 70 percent of nominal capacity is excellent. The performance is even more remarkable in terms of the pioneering nature of the plant; this particular type of stoker was invented only 16 years ago and this is the first large plant ever built using this principle.

Table 3-3a is a summary of the year's operating data for 1976 as printed from the data storage and analysis system.

TABLE 3-3a. DUESSELDORF WASTE-BURNING FACILITY--OPERATING RESULTS - 1976

Waste Input		
Residential Waste	180,462.80	Tonnes
Industrial Waste	65,795.35	Tonnes
Bulky Waste (Residential and Industrial)	25,250.79	Tonnes
Rubbish	10,844.80	Tonnes
Waste Oil	1,831.54	Tonnes
Total	284,185.37	Tonnes
Heating Oil	20.81	Tonnes
Consumption		
Waste	284,185.37	Tonnes
Heating Oil	3.40	Tonnes
Storage		
Waste	2,475.00	Tonnes
Heating Oil	26.84	Tonnes
Heat Value		
Waste	1,815.98	kcal/kg
Heating Oil	10,155.03	kcal/kg
Sulfur		
Heating Oil	0.43	Percent
Wet Residue		
Fine	78,706.30	Tonnes
Discarded	19,650.28	Tonnes
Total Residue	98,356.58	Tonnes
Total Residue Shipped	97,641.58	Tonnes
Storage	935.00	Tonnes
Residue Analysis		
Water	18.89	Percent
Combustible	5.03	Percent
Scrap Iron		
Total	8,492.42	Tonnes
Bulky Scrap	531.51	Tonnes

TABLE 3-3a. (Continued)

Electricity Consumption		
Total Received	14,521.00	MWH
Maximum Electrical Demand	2,445.00	KW
Consumption		
City Water	99,253.00	Cubic Meter
Well Water	507,671.00	Cubic Meter
Total Water	606,924.00	Cubic Meter
Time of Operation of all Boilers	30,963.00	Hours
Waste Feed		
Number of Crane Loads Charged	125,939.00	
Live Steam		
Pressure	81.26	Bar
Temperature	471.90	°C
Amount	592,265.00	Tonnes
Enthalpy of Steam	795.06	kcal/kg
Enthalpy of Feedwater	130.71	kcal/kg
Flue Gas Temperature	270.00	°C
Oxygen (O_2) Content		
Left Side of Furnace	8.88	Percent
Right Side of Furnace	8.88	Percent
Air Temperature		
Ambient	11.00	°C
Entering Preheater	25.00	°C
Leaving Preheater	87.00	°C
Heat Balance		
Live Steam	470,885.32	Gcal
Exhaust Gas	94,749.74	Gcal
Combustible in Residue	18,673.44	Gcal
Sensible Heat in Residue	12,702.76	Gcal
Piping and Radiation Loss	13,322.98	Gcal
Total	610,334.24	Gcal

TABLE 3-3a. (Continued)

Heat Input		
Heat in Feedwater	77,414.96	gcal
Heat in Combustion Air	16,810.26	gcal
Heat From Heating Oil	34.53	gcal
Heat From Waste	516,074.50	gcal
Boiler Efficiency	73.83	Percent
Energy Losses		
Exhaust Gas	17.78	Percent
Unburned Combustible	3.50	Percent
Sensible Heat in Residue	2.38	Percent
Piping and Radiation Loss	2.50	Percent
Consumption and Operating Rates		
Heating Oil	0.11	kg/hour
Waste (aver. per unit operating)	9.18	tonnes/hour
Crane Lift Rate	2.26	tonnes/grab
Heat Release	16.67	Gcal/hour
Live Steam Rate		
Total	19.13	tonnes/hour
Produced From Oil	1.34	kg/hour
Produced From Waste	19.13	tonnes/hour
Production Rates		
Steam Per Unit Fuel	2.08	kg/kg
Steam Per Unit Waste	2.08	kg/kg
Steam Per Unit Oil	12.19	kg/kg
Residue Per Unit Waste	0.37	kg/kg
Total Water Consumption	2.14	Cubic Meter/tonne
Electricity Consumption		
Per Tonne Total Waste	51.10	kwh/tonne
Per Tonne Steam	24.52	kwh/tonne
Steam Sold *	564,091.00	Tonnes

* Corrected to 807 Kcal/kg

POLLUTION CONTROL ASSESSMENT

The stack plume from this plant was usually slightly visible as a very light, thin gray cloud against a clear blue sky. It dissipated quickly and did not appear to be objectionable. The emission appeared to be within the allowable limit.

In 1974 a new Federal regulation of atmospheric emissions was enacted known as TA Luft (Technischen Anleitung zur Reinhaltung der Luft). It reduced the allowable particulate emission for plants over 100,000m^3/h (58,850 cfm) to 100 mg/Nm^3 corrected to 11 percent CO_2. For new plants it also specifies limits for emission of CO, NO_2 and SO_2. For plants which expand by adding new capacity, all of the old and new equipment must meet following new limits on gases (at o C, 32F):

HCl: 100 mg/Nm^3 (62 ppm) [0.083 lb/1000 lb gas]
HF: 5 mg/Nm^3 (11 ppm) [0.008 lb/1000 lb gas]
SO_2: 100 mg/Nm^3 (^{2}175 ppm) [0.46 lb/1000 lb gas].
CO: 1g/Nm^3

Requirements for SO_2 reduction are made according to ambient air quality. In case that SO_2 reduction is necessary the limit is 100 mg/Nm^3.

Since 1973 the gaseous emissions from this plant have been checked periodically. The most recent average is as follows (all corrected to 11 percent CO_2):

	mg/Nm^3	ppm (by Vol at o c, 32.)
HCl	1000	623
HF	9	10
SO_2	500	175
SO_3	5	2
NO_x (as NO_2)	9	4
Oxygen	11 percent	

Evidently if Boiler No. 6 were to be installed the levels of HCl and HF now produced would require that all 6 boilers be equipped with scrubbers to remove most of these gases. This poses a difficult dilemma for this and similar existing plants. Although both HCl and HF are readily soluble in water, the operation of large scrubbers to remove these gases reliably has yet to be demonstrated. Corrosion by the acids formed is still a major problem with the few such scrubbers that have been tried on a large scale. Hopefully the new plants which are encountering major problems with their scrubbers will in a few years find practical answers which will show the way for older and future plants. Meanwhile, since ambient air measurements of HCl and HF are not usually made it would seem that the regulation is premature both from the standpoints of demonstrated need and demonstrated control technology.

Noises

This plant is located in an industrial area adjacent to a major railroad line, hence its noise is not a major problem. However, in 1972 because of complaints over noise from the outdoor induced axial flow fans, the fans were replaced by sound treated ones at a cost of 300,000 DM each ($129,000 at 2.32 DM/$ in 1973).

PERSONNEL AND MANAGEMENT

Table 3-4 shows the organization of the 83 persons who constitute the plant staff. The plant operates on a 4-shift per day basis with the average work week 43 hours. Normally there are 9 workers handling the operation per shift. Job descriptions are published annually and key workers have an organization handbook.

The following principal operators are connected by an inter-communication system:

Crane operator
Boiler operator
Shear operator
Shredder operator
Tipping Floor (2 locations).

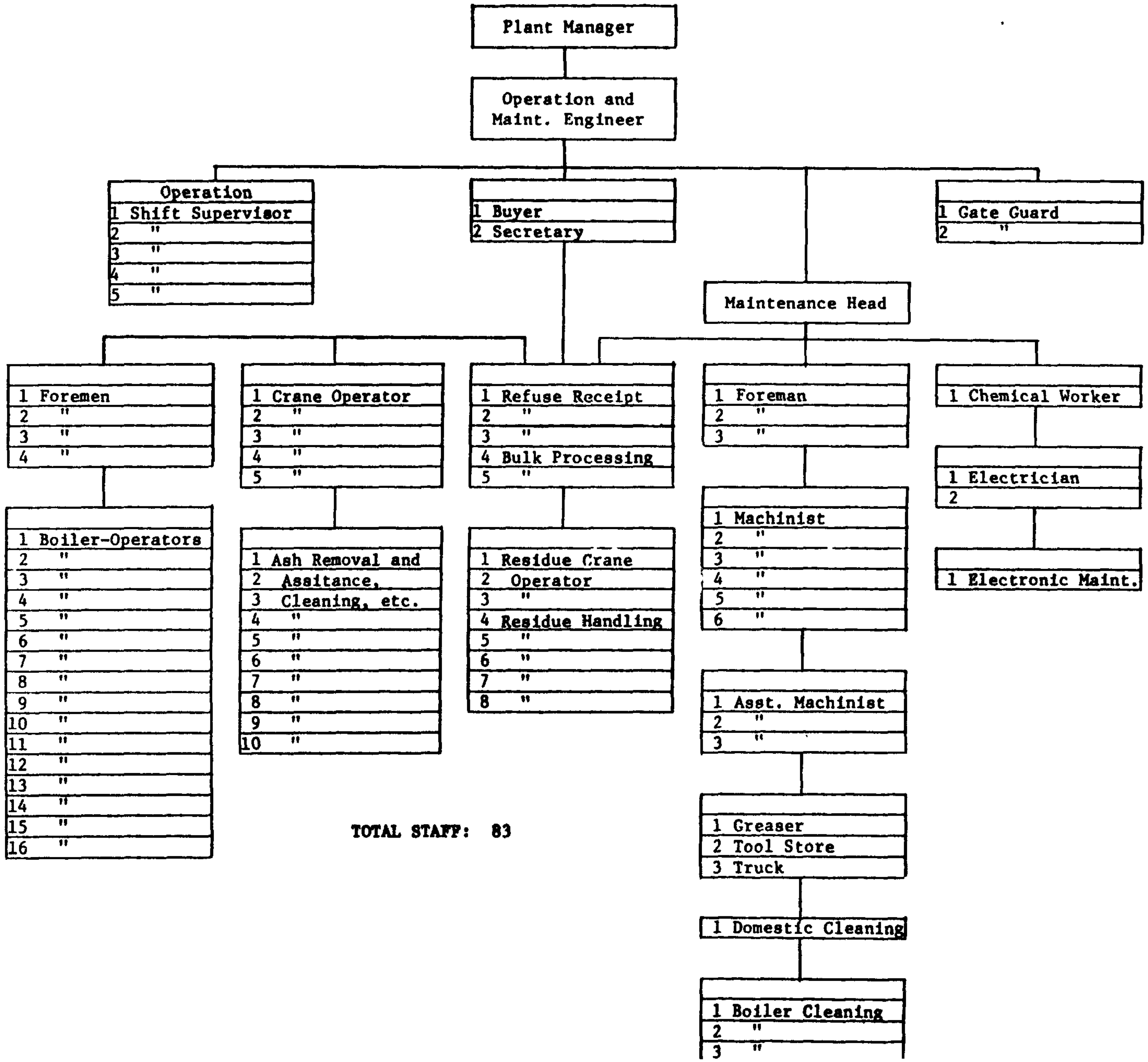
Training

Crane Operator. One year general plant training plus one year special training followed by examination for an operators license. No special prior education or experience is required.

Boiler Operator. An effort is made to recruit those having mechanical training from a 3-year apprenticeship. At this plant he starts as a boiler operator's apprentice for 2 years. Their additional training is given 6 hours per week. Then the Technischer Überwachungs Verein (TÜV) provides a 6-month course, 3 hours per week to prepare for examination for a boiler operator's license.

Separately the VGB (Association for Large Power Plant Operators), conducts an on-the-job training program for power plant operators. Prerequisite for this training is 6 years experience on boilers, turbines, coal handling, water treatment or similar power-oriented work.

TABLE 3-4. STAFF ORGANIZATION AT STADTWERKE DUESSELDORF WASTE-TO-ENERGY PLANT



The VGB course totals 1500 hours. Without prior training this course must be matched by 8 years experience. Then successful completion of a VGB-administered examination qualifies him as a Kraftwerker (Power Plant Worker). Shift foremen must have this rank. After one year of additional experience he may become eligible for a one-year course at the VGB school in Essen, at the successful conclusion of which he becomes a Kraftwerkmeister (Master Power Plant Worker).

Pay scales are developed in negotiation with the workers union. Following are the approximate monthly pay rates including 28 to 30 percent for pension and taxes:

Shift supervisor	DM 4600
Shift workers	DM 3300
Crane operator	DM 3300
Foreman	DM 3400
Boiler cleaner	DM 3200
Senior boiler operator	DM 3050
Apprentice boiler operator	DM 2800
Power plant operator	DM 3150
Ash handler	DM 2600-2800
Electrician	DM 2300
Shop foreman	DM 2600

The Boiler Cleaner is paid a relatively high rate because it is difficult, odd time work.

For the average worker at DM 3000/month, less 30 percent for pension and taxes, his annual takehome pay is 25,000 DM ($10,584 at $0.42/DM).

ENERGY MARKETING

Although the refuse plant does no marketing because it has only one customer, Stadtwerke Düsseldorf AG, the latter does advertise and has an appliance sales outlet. Aside from selling electricity it also sells distric heating, gas and water. There are about 50 in its sales force. The Stadtwer Düsseldorf AG was converted to a stock company in 1972.

In the district heating system the customer is billed annually but pays on a monthly budget plan. The contract for heating is reviewed annually. The rate is reduced if the customer helps reduce peak demands by installing a heated rock heat storage tank.

The district heating loop in Garath, a new housing area, was installed and paid for by Stadtwerke Düsseldorf as was also the loop for the new Dusseldorf University but customers contribute to loop costs. The supply comes from the base load power station "Lansword" on the river Rhine.

ECONOMICS

Capital Investment

The first four units and associated structures built in 1965 cost DM 34.5 x 10^6 (\$8.63 x 10^6 at 4.00 DM/\$-1965)[\$14.5 x 10^6 at 2.35 DM/\$-1977]. This cost was divided as follows:

Mechanical equipment	DM 15.5 x 10^6
Electrical	1.6
Structures, roads, landscaping	12.0
	29.7
Construction financing over 2 years and site development	5.4
TOTAL	DM 34.5 x 10^6

When the larger unit No. 5, was added within the existing building in 1972 it cost 11.7 x 10^6 DM (\$3.67 x 10^6 at 3.19 DM/\$-1972)[\$4.91 x 10^6 at 2.38 DM/\$-1977]. Part of this proportionately higher cost was the result of a new precipitator and shredder installed at that time. The cost breakdown in 1972 was:

Mechanical equipment	DM 6.5×10^6
Electrical (including precipitator)	1.77
Structural changes	0.41
Shredder	1.6
Engineering fee (2.5%)	0.22
Escalation cost	1.3
	DM 11.70×10^6

Mr. Thoemen estimated if No. 5 were built today (1977) it would cost 20×10^6 DM (\$$8.4 \times 10^6$) because of inflation. If all five units were built today the plant would cost 80-90 $\times 10^6$ DM (\$34-38 $\times 10^6$). If No. 6 were built today in the space already available for it in the existing building with a maximum capacity of 360 tonnes/day it would cost an estimated 27×10^6 DM (\$$11.3 \times 10^6$) including a fourth precipitator and a flue-gas scrubber system for the entire plant composed of 4 scrubber modules in parallel. Mr. Thoemen's experience is that no one plant unit should be designed for more than 15 tonnes/hr, (360 tonnes/day) [396 tons/day) because if a breakdown reduces plant capacity, the accumulation in storage of more than 360 tonnes per day will rather quickly force hauling the excess to distant landfills, a fairly expensive operation.

The above costs expressed per tonne (ton) day of capacity were as follows:

	DM per tonne-day in DM for year built	\$ per ton-day in \$ for year built	\$ per ton-day if built in 1977
1965 No. 1-4 (includ. building	35,938	8,990	15,109
1972 No. 5 (without building)	39,000	12,233	16,367
1977 If No. 6* were built(est)	75,000	31,390	31,390

Because this plant generates only high-pressure steam and not electricity these costs are low for most plants of this size which do have the equipment to generate electricity. It appears that the German requirement for removal of HCl and HF by means of scrubbers will raise plant costs substantially.

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* Including 1 el. precipitator and scrubbing system for all 6 units.

The land area required for this operation is as follows:

Structures	7,000 m^2
Landscape	8,000 m^2
Roads	15,331 m^2
	30,831 m^2 (331,862 ft^2)[7.5 acres]

The value of this property is estimated in 1977 terms as 7.7 x 10^6 DM ($3,234,000). It is of considerable significance that if this same expensive industrial property were utilized as a sanitary landfill, it would have become filled in about 2 or 3 years at the average rate this plant is now operating (290,000 tonnes/yr or 319,000 tons/yr).

Operating Costs

In 1975, the operation and maintenance costs, not including amortization or interest on debt, totalled 9.066 x 10^6 DM ($3.808 at 2.38 DM/$). This consisted of 4.215 x 10^6 DM for operation and 4.85 x 10^6 DM for maintenance. Maintenance was divided as follows:

	Millions DM	Millions 1977 Dollars
Maintenance by plant staff	1.139	0.478
Maintenance by outside contractors	2.481	1.042
Maintenance materials	1.231	0.517
TOTAL	4.851	2.037

Added to these costs is a 5 percent management fee, which the "Stadtwerke Düsseldorf" charges the department of Sanitation as a management fee, and 5 percent debt cost. Thus, the total charge to the owner for the operation and maintenance in 1976 was 10.822x 10^6 DM ($4.545 x 10^6 at 2.38 DM/$). Including capital costs and misc. expenses 1976 total gross costs per tonne of refuse were: DM - 63,86. Net costs (revenues are included) were: DM - 30,67 per tonne. The total refuse burned in 1976 was 286, 185 tonnes (312,604 tons).

Tables 3-5 through 3-9 showing the operating costs (and revenues) for the plant in 1975 were provided by Dr. Helmut Orth, Direktor, Stadtreinigungs- und Fuhramt (Deaprtment of Sanitation and Streets).

TABLE 3-5. DUESSELDORF WASTE-BURNING FACILITY - 1975

	Amount in Tonnes	Percent of Throughput	Percent of Input	Weight, Tonnes
Type of Waste				
Residentual	201,816	67.87		
Bulky	9,014	3.03		
Rubbish	10,024	3.37		
Industrial	74,837	25.17		
Contaminated Oil	1,668	0.56		
Total Waste	297,359	100.00		
Residues From Burning				
Ash			35.3	105,092
Baled Scrap			3.1	5,986
Loose Scrap			--	3,192
Total Residue			38.4	114,278

TABLE 3-6. COSTS OF THE WASTE BURNING FACILITY, 1975

	DM	Percent
Operating Expense Including 80 Percent Overhead on Salaries and Wages and 10 Percent Overhead on Other costs	2,707,858.03	16.19
Maintenance Expense with Overhead	4,216,217.39	25.19
Miscellaneous Expense with Overhead	763,636.37	4.56
Operational Fee Surcharge of 5 Percent Without Electricity, Water, or Fuel	256,511.93	1.53
Management Fee of Sanitation Department	321,157.70	1.92
Insurance	130,190.00	0.78
Electricity, Water	1,267,719.68	7.57
Fuel	2,152.85	0.01
Ash and Scrap Hauling	126,695.16	0.76
Amortization	6,944,611.78	41.49
TOTAL	16,736,650.89	

TABLE 3-7. COSTS FOR WASTE COLLECTION AND TRANSPORT INCLUDING BULKY WASTE HAULED BY FOUR SIZES OF VEHICLE

Salaries	DM	1,759.173.24	6.49%
Operating Wages	DM	17.302.664.26	63.85%
Materials	DM	845.009.56	3.12%
Motor Fuel	DM	488.747.19	1.80%
Special Charges	DM	2.694.862.82	9.94%
Interest	DM	597.459.89	2.20%
Repair Wages	DM	680.020.98	2.51%
Repair Supplies	DM	416.634.60	1.54%
Contracted Repair	DM	180.231.16	0.67%
Amortization	DM	2.134.280.09	7.88%
	DM	27.099.083.79	100.00%

TABLE 3-8. COST SUMMARY OF REFUSE HANDLING INCLUDING COSTS OF BURNING AND LANDFILL DISPOSAL, 1975

Collection and Transport	DM	27.099.083.79	80.73%
Burning	DM	6.324.975.06	18.84%
Landfill	DM	143.375.00	0.43%
TOTAL	DM	33.567.443.85	100.00%

TABLE 3-9. DUSSELDORF WASTE BURNING FACILITY 1966-1975

		1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Waste Input	tonnes	203.638	235.816	256.714	263.671	265.134	242.812	266.519	288.863	298.183	297.359	284.185
Industrial Waste	tonnes	20.330	46.499	57.562	64.649	74.306	73.649	71.374	70.488	77.381	74.837	81.725
Ratio Industrial to Total	%	10	19,7	22,4	24,5	20,4	30,3	26,8	24,4	26	25,2	28,8
Average Heat Value	kcal/kg	1.371	1.456	1.551	1,601	1.638	1.715	1.758	1.687	1.586	1.746	1.816
Steam Delivered at 80 bar and 500 C	tonnes	297.306	357.288	395.351	423.147	427.958	426.085	485.361	512.281	492.772	560.002	564.091
Steam Delivered per tonne of Waste	tonnes	1,46	1,52	1,54	1,60	1,61	1,75	1,82	1,77	1,65	1,88	1,00
Net Burning Cost	DM	12,--	13,--	13,25	13,45	12,78	16,60	16,61	22,15	24,88	25,48	

TABLE 3-9. DUESSELDORF WASTE BURNING FACILITY, 1966-1976

		1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Waste Input	tonnes	203.638	235.816	256.714	263.671	265.134	242.812	266.519	288.863	298.183	297.359	284.185
Industrial Waste	tonnes	20.330	46.499	57.562	64.649	74.306	73.649	71.374	70.488	77.381	74.837	81.725
Ratio Industrial to Total	%	10	19,7	22,4	24,5	20,4	30,3	26,8	24,4	26	25,2	28,8
Average Heat Value	kcal/kg	1.371	1.456	1.551	1,601	1.638	1.715	1.758	1.687	1.586	1.746	1.816
Steam Delivered at 80 bar and 500 C	tonnes	297.306	357.288	395.351	423.147	427.958	426.085	485.361	512.281	492.772	560.002	564.091
Steam Delivered per tonne of Waste	tonnes	1,46	1,52	1,54	1,60	1,61	1,75	1,82	1,77	1,65	1,88	1,00
Net Burning Cost	DM	12,--	13,--	13,25	13,45	12,78	16,60	16,61	22,15	24,88	25,48	

(1) Some of the steam generated is used internally. In 1976 this totalled 4.76 o/o of total steam.

For private haulers who deliver refuse to the plant, the following charges apply:

	DM/Tonne	$/Ton
Residential Waste	26	9.90
Industrial Waste	30	11.40
Bulky Waste	35	13.40
Tires	41	15.70
Oil contaminated soil	52	19.90

Revenues

Income to the plant comes from the sale of steam, residue, and scrap iron.

The city power system considers the value of the steam received is 1.017 times the cost of the coal that would be needed to generate that steam. In 1977, that amounts to @ 15 DM/tonne ($6.30/ton) of steam ($2.86/ 1,000 lb).

Table 3-10 shows the plant income in 1975.

Figure 3-13 shows two inclined conveyors removing baled scrap from the processing plant. Figure 3-14 is a close-up of the baled scrap which, according to Table 3-10, sold in 1975 for an average of 107.50 DM per tonne ($45.18 per ton at 2.38 DM/$).

Figure 3-15 pictures Mr. Thoemen, in white helmet, answering questions of the visiting team while standing in the sized residue storage area. As shown in Table 3-10, this fines residue was sold in 1975 for an average price of 1.01 DM/tonne ($0.39/ton). The affiliated company sells a portion of the residue for 9 DM/tonne ($3.44/ton).

TABLE 3-10. INCOME TO THE WASTE BURNING FACILITY IN 1975

	GROSS WEIGHT TONNES	NET WEIGHT TONNES	COST PER TONNE, DM	COST, DM
Steam	590.814	560.002	14.51	8.125.629.02
Scrap		9.180	107.52	986.987.75
Ash	105.092	48.000	1.01	48,596.25
TOTAL INCOME				9,161.213.02

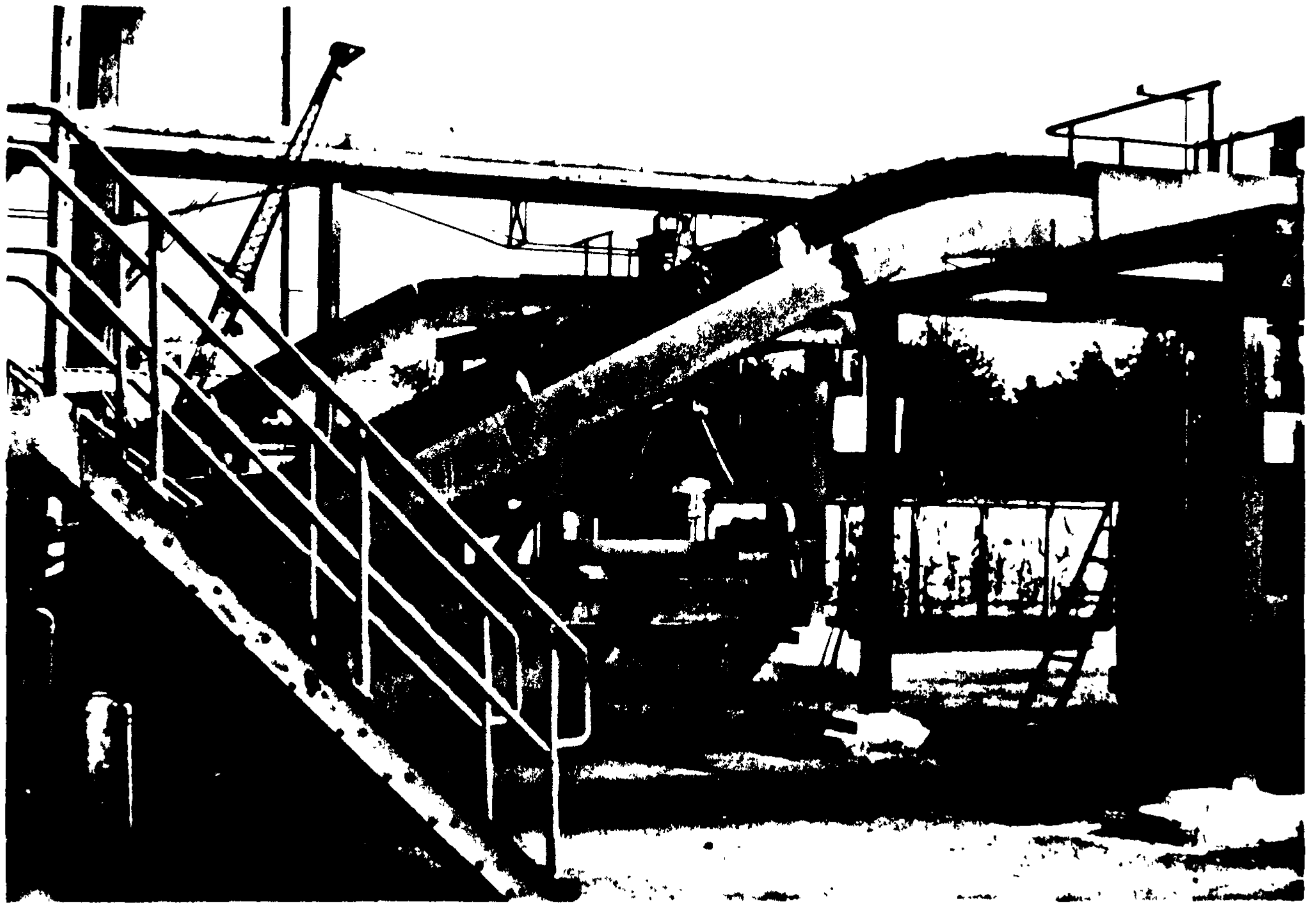

FIGURE 3-13. INCLINED CONVEYORS REMOVING BALED SCRAP (Battelle Photograph)

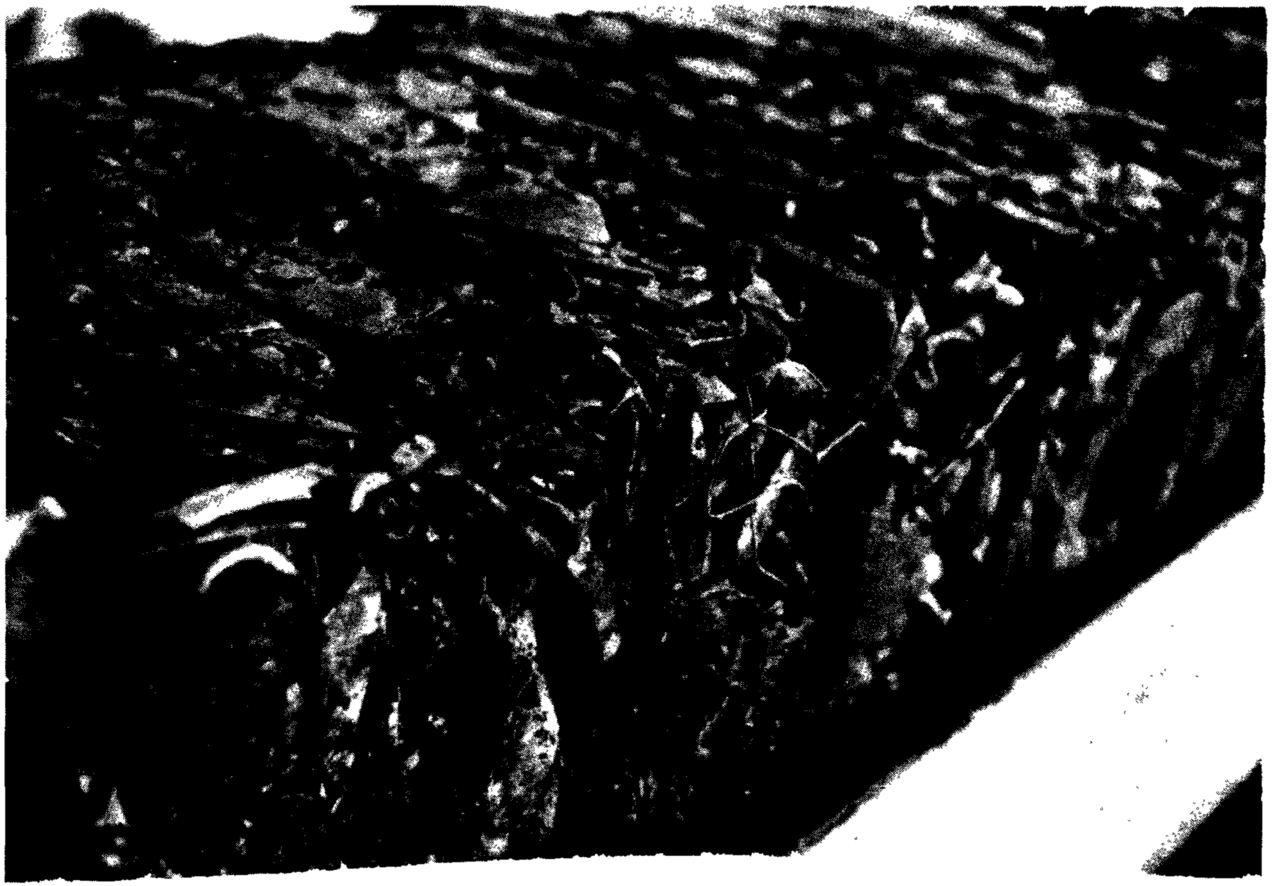

FIGURE 3-14. CLOSE-UP OF BALED STEEL SCRAP (Battelle Photograp

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
Btu	kilocalorie	0.252	kilocalorie	Btu	3.968
MBtu	Gcal	0.252	Gcal	MBtu	3.968
Btu	kilowatt-hours	0.000293	kilowatt-hours	Btu	3414
Btu	Joules	1055.1	Joules	Btu	0.000948
Btu per pound	kilocalories per kilogram	0.5555	kilocalories per kilogram	Btu per pound	1.8
Btu per pound	Joules per kilogram	2326	Joules per kilogram	Btu per pound	0.00430
Btu per hour	watts	0.29307	watts	Btu per hour	3.413
Btu per sq ft-hr	kilocalories per sq meter-hr	2.711	kilocalories per sq meter-hr	Btu per sq ft-hr	0.3688
Btu per cu ft-hr	kilocalories per cu meter-hr	8.897	kilocalories per cu meter-hr	Btu per cu ft-hr	0.112
pounds per 1000 pounds (gas)	grams per cu meter	1.205	grams per cu meter (gas)	pounds per 1000 pounds	0.93
grains per cu ft (68 F)	grams per cu meter (20 C)	2.28	grams per cu meter (20 C)	grains per cu ft (68 F)	0.43

TABLE . EXCHANGE RATES FOR SIX EUROPEAN COUNTRIES, (NATIONAL MONETARY UNIT PER U.S. DOLLAR) 1948 TO FEBRUARY, 1978(a)

	Denmark Kroner (D.Kr.)	France Francs (F.Fr.)	W. Germany Deutsch Mark (D.M.)	Netherlands Guilders (Gl.)	Sweden Kronor (S.Kr.)	Switzerland Francs (S.Fr.)
1948	4.810	2.662	3.333	2.653	3.600	4.315
1949	6.920	3.490	4.200	3.800	5.180	4.300
1950	6.920	3.499	4.200	3.800	5.180	4.289
1951	6.920	3.500	4.200	3.800	5.180	4.369
1952	6.920	3.500	4.200	3.800	5.180	4.285
1953	6.920	3.500	4.200	3.786	5.180	4.288
1954	6.914	3.500	4.200	3.794	5.180	4.285
1955	6.914	3.500	4.215	3.829	5.180	4.285
1956	6.914	3.500	4.199	3.830	5.180	4.285
1957	6.914	4.199	4.202	3.791	5.173	4.285
1958	6.906	4.906	4.178	3.775	5.173	4.308
1959	6.908	4.909	4.170	3.770	5.181	4.323
1960	6.906	4.903	4.171	3.770	5.180	4.305
1961	6.886	4.900	3.996	3.600	5.185	4.316
1962	6.902	4.900	3.998	3.600	5.186	4.319
1963	6.911	4.902	3.975	3.600	5.200	4.315
1964	6.921	4.900	3.977	3.592	5.148	4.315
1965	6.891	4.902	4.006	3.611	5.180	4.318
1966	6.916	4.952	3.977	3.614	4.180	4.327
1967	7.462	4.908	3.999	3.596	5.165	4.325
1968	7.501	4.948	4.000	3.606	5.180	4.302
1969	7.492	5.558	3.690	3.624	5.170	4.318
1970	7.489	5.520	3.648	3.597	5.170	4.316
1971	7.062	5.224	3.268	3.254	4.858	3.915
1972	6.843	5.125	3.202	3.226	4.743	3.774
1973	6.290	4.708	2.703	2.824	4.588	3.244
1974	5.650	4.444	2.410	2.507	4.081	2.540
1975	6.178	4.486	2.622	2.689	4.386	2.620
1976	5.788	4.970	2.363	2.457	4.127	2.451
1977	5.778	4.705	2.105	2.280	4.670	2.010
1978 (Feb.)	5.580	4.766	2.036	2.176	4.615	1.987

(a) Exchange Rate at end of period.

Line "ae" Market Rate/Par or Central Rate.

Source: International Financial Statistics: 1972 Supplement; April, 1978, Volume XXXI, No. 4, Published by the International Monetary Fund.

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FIGURE 3-15. VISITORS DISCUSSING FINE ASH RESIDUE USES NEAR STORAGE AREA (Battelle Photograph)

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(6) Feindler, Klaus. S., and Thoemen, K-H., "308 Billion Ton-Hours of Refuse Power Experience", Presented to ASME 8th National Waste Processing Conference, Chicago, Illinois, May 7-10, 1978.

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
feet	meters	0.3048	meters	feet	3.281
square feet	square meters	0.0929	square meters	square feet	10.76
cubic feet	cubic meters	0.0283	cubic meters	cubic feet	35.31
inches	millimeters	25.4	millimeters	inches	0.0394
cubic yards	cubic meters	0.7646	cubic meters	cubic yards	1.308
barrels (oil)	cubic meters	0.15899	cubic meters	barrels (oil)	6.290
miles	kilometers	1.609	kilometers	miles	0.6214
square miles	square kilometers	2.589	square kilometers	square miles	0.3861
acres	square kilometers	0.004047	square kilometers	acres	247.1
acres	hectares	0.4047	hectares	acres	2.471
gallons	cubic meters	0.003785	cubic meters	gallons	264.2
ton (short)	tonne (metric)	0.9078	tonne (metric)	ton (short)	1.102
pounds	grams	454	grams	pounds	0.002046
grains	grams	0.0648	grams	grains	15.42

Revised Dec. 78

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
pounds per million Btu	nanograms per Joule	499.2	nanograms per Joule	pounds per million Btu	0.0023
pounds per million Btu	milligrams per megajoule	499.2	milligrams per megajoule	pounds per million Btu	0.00233
cubic feet per minute	cubic meters per hour	1.699	cubic meters per hour	cubic feet per minute	0.588
gallons per minute	liters per minute	3.785	liters per minute	gallons per minute	0.264
pounds per square foot	kilograms per square meter	703.1	kilograms per square meter	pounds per square foot	0.001422
pounds per square inch	kilograms per square centimeter	0.07031	kilograms per square centimeter	pounds per square inch	14.223
pounds per square inch	atmospheres	0.0681	atmospheres	pounds per square inch	14.69
pounds per square inch	newtons per square meter	6894.8	newtons per square meter	pounds per square inch	0.00014
pounds per square inch	kilopascals	6.8948	kilopascals	pounds per square inch	0.1450
atmospheres	bars	1.0133	bars	atmospheres	0.9869
atmospheres	kilopascals	101.3	kilopascals	atmospheres	0.0098
pounds per square inch	bars	0.06895	bars	pounds per square inch	14.50
inches of water	pascals	249.08	pascals	inches of water	0.004015
millimeters of water	pascals	9.806	pascals	millimeters of water	0.102