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European Refuse Fired Energy Systems

Evaluation of Design Practices

Volume 15

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EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

Wuppertal Refuse Fired Power Plant
Wuppertal, West Germany

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Volume 15

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Peter Ahrens, plant financial manager

Edgar Buchholz, plant technical manager*

Volkswirt Horst Masanek, plant commercial manager**

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* Mr. Buchholz was interviewed on a previous October, 1976 trip.

** Mr. Masanek was not interviewed but should be mentioned because of his responsibilities.

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:

VOLUME I

A EXECUTIVE SUMMARY
B INVENTORY OF WASTE-TO-ENERGY PLANTS
C DESCRIPTION OF COMMUNITIES VISITED
D SEPARABLE WASTE STREAMS
E REFUSE COLLECTION AND TRANSFER STATIONS
F COMPOSITION OF REFUSE
G HEATING VALUE OF REFUSE
H REFUSE GENERATION AND BURNING RATES PER PERSON
I DEVELOPMENT OF VISITED SYSTEMS

VOLUME II

J TOTAL OPERATING SYSTEM RESULTS
K ENERGY UTILIZATION
L ECONOMICS AND FINANCE
M OWNERSHIP, ORGANIZATION, PERSONNEL AND TRAINING

VOLUME III

P REFUSE HANDLING
Q GRATES AND PRIMARY AIR
R ASH HANDLING AND RECOVERY
S FURNACE WALL
T SECONDARY (OVERFIRE) AIR

VOLUME IV

U BOILERS
V SUPPLEMENTARY CO-FIRING WITH OIL, WASTE OIL AND SOLVENTS
W CO-DISPOSAL OF REFUSE AND SEWAGE SLUDGE
X AIR POLLUTION CONTROL
Y START-UP AND SHUT-DOWN
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SUMMARY

In several ways the Wuppertal plant is unique. It is so new (1976) that it is not yet fully operational. It promises to be a successful operation if enough additional waste can be supplied to effect economies of scale. It is perched on a hillside, remote from the city, which undoubtedly increased its foundation and construction costs. A meandering road, serving the plant only, connects it to the roadway network. It is located directly above a public swimming pool in the adjacent valley which will demand very clean, quiet operation in the summer season. No community heat is supplied but electricity for city use is generated seven days per week. The residue is sold to a private processor located in a valley adjacent to the plant and apparently a ready market is found for most of the sized residue. A scrubber system is being installed to meet federal regulations of HCl and HF emission. Meanwhile, the plant has operated at little over half capacity, hence initial unit costs are high.

STATISTICAL SUMMARY

Community description:	
Area (square kilometers)	100
Population (number of people)	444,000
Key terrain feature	very hilly
Solid waste practices:	
Total waste generated per day (tonnes/day)	---
Waste generation rate (Kg/person/day)	0.9
Lower heating value of waste (Kcal/kg)	1900-2600
Collection period (days/week)	5-1/2
Cost of collection (local currency/tonne)	---
Use of transfer and/or pretreatment (yes or no)	No
Distance from generation centroid to:	
Local landfill (kilometers)	---
Refuse fired steam generator (kilometers)	adjacent
Waste type input to system	M.S.W. & Industrial
Cofiring of sewage sludge (yes or no)	No
Development of the system:	
Date operation began (year)	1976
Plant architecture:	
Material of exterior construction	concrete
Stack height (meters)	70
Refuse fired steam generator equipment:	
Mass burning (yes or no)	yes
Waste conditions into feed chute	
Moisture (percent)	---
Lower heating value (Kcal/kg)	1900-2600 Kcal/kg
Volume burned:	
Capacity per furnace (tonnes/hr)	15
Number of furnaces constructed (number)	4

Capacity per system (tonnes/day)	1440 max
Actual per furnace (tonnes/ hr)	13
Number of furnaces normally operating (number)	2
Actual per system (tonnes/day)	624
Use auxiliary reduction equipment (yes or no)	Yes , for bulky refuse only
Pit capacity level full:	
(Tonnes)	---
(m^3)	10,000 max. 18,000
Crane capacity:	
(tonnes)	10 ea.
(m^3)	7
Feeder drive method	Hydraulic
Burning grate:	
Manufacturer	Vereinigte Kesselwerke
Type	Roller
Number of sections (number)	6
Length overall (m) effective	14.27
Width overall (m)	3.5
Primary air-max (Nm^3/hr)	97,200
Secondary air-overfire air-max (Nm^3/hr)	19,800
Furnace volume (m^3)	
Furnace wall tube diameter (mm)	57
Furnace heating surface (m^2)	
Auxiliary fuel capability (yes or no)	Yes
Use of superheater (yes or no)	Yes
Boiler	
Manufacturer	Vereinigte Kesselwerke
Type	Natural Circulation
Number of boiler passes (number)	4
Steam production per boiler (kg/hr)	46,000
Total plant steam production (kg/hr)	actual 90,000
Steam temperature (C)	350
Steam pressure (bar)	28.4

Use of economizer (yes or no)	Yes
Use of air preheater (yes or no)	No
Use of flue gas reheater (yes or no)	No
Cofire (fuel or waste) input	No
Use of electricity generator (yes or no)	Yes
Type of turbine	condensing
Number of turbines (number)	2
Steam consumption (kg/hr)	107,000
Electrical production capacity per turbine (kw)	20,000
Total electrical production capacity (kw)	40,000
Turbine back pressure (bar)	0.12
User of electricity ("Internal" and/or "External")	Both
Energy Utilization:	
Medium of energy transfer	None
Temperature of medium (C)	
Population receiving energy (number)	
Pressure of medium (kg/m^2)	
Energy return medium	
Pollution control:	
Air:	
Furnace exit conditions	
Gas flow rate (m^3/hr)	100,000
Furnace exit loading (mg/Nm^3)	

COMMUNITY DESCRIPTION

Geography

The area of Wuppertal-Remschied, Figure 4-1, is extremely hilly. It has an area of approximately 100 km^2 (38.6 mi^2), the center of which is about 28 km (17.4 mi) east of Duesseldorf. Population density is approximately 5440/km^2 (2100/mi^2). Manufacturing is the predominant productive activity in the area.

In 1929, the city of Wuppertal had been formed by the combination of two cities in the narrow valley (tal) of the Wupper River--Barmen, population 187,000 and Elberfeld, population 112,000. The area of Barmen stretches along 4 mi (6.5 km) of the Wupper. High wooded hills surround it.

At Barmen in 1907, the first municipal incinerator in Germany was built. It operated for about 40 years.

Government and Industry

Barmen, which became part of Wuppertal in 1929, was one of the most important manufacturing centers of Germany early in the century. Ribbon weaving was the chief industry; chemicals, buttons, rugs, and pianos were also made.

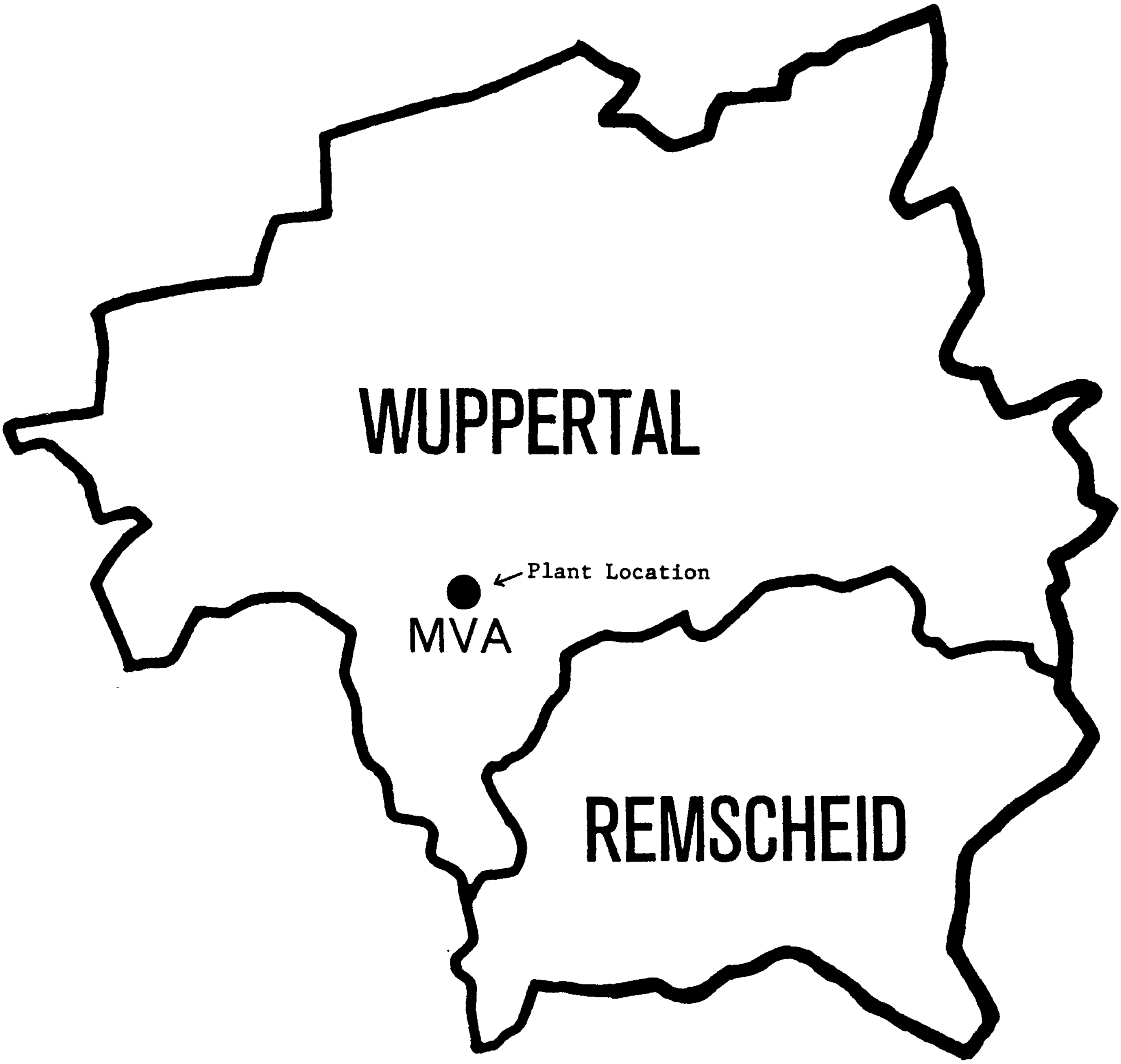

FIGURE 4-1. REGION SERVED BY WUPPERTAL MVA (MULLVERBRENUNGSANLAGE) [WASTE-BURNING PLANT]
(Courtesy MVA Wuppertal Gmbh)

SOLID WASTE PRACTICES

Solid Waste Generation and Collection Activities

Figure 4-2 shows the vicinity of the Wuppertal plant.

Public collection vehicles collect household refuse once per week and deliver it to the plant 7 hours per day, 5 days per week at the rate of 110,000 tonnes (121,000 tons) per year. Private vehicles handling primarily commercial and industrial waste deliver to the plant 8 hours per day, 5-1/2 days per week at the rate of 68,000 tonnes (74,800 tons) per year. The plant burns refuse 7 days per week. Of the publicly-collected waste, about 94,000 tonnes (103,400 tons) per year is generated by Wuppertal and 16,000 tonnes (17,600 tons) per year by Remscheid. The total public and private collection--178,000 tonnes/yr (195,800 tons/yr)--corresponds to a generation rate of 0.9 kg/capita-day (2 lb/capita-day).

Private vehicles must dump into special containers for that purpose which are later picked up and emptied into the pit.

Solid Waste Transfer and/or Pretreatment

There are no transfer stations. There is no pretreatment of waste except for bulky waste which is cut up by a Lindemann hydraulically driven shear adjacent to the refuse pit.

Solid Waste Disposal

Plant residue is processed by a private company at the foot of the hill on which the plant is located. Discards from that processing are deposited in a sanitary landfill immediately adjacent to the residue processing plant.

FIGURE 4-2. PRIVATE ROADWAY LEADING TO THE WEIGH STATION FOR THE WUPPERTAL PLANT

DEVELOPMENT OF THE SYSTEM

The two industrial communities of Wuppertal and Remscheid, population 409,000 and 135,000, respectively, began discussion in 1969 and 1970 on the possibilities for a combined facility for disposal of their solid wastes. At first, the deep valley adjacent to the present plant site was considered for landfill because it contained a water-filled quarry later abandoned in 1973. However, the life of that landfill was estimated to be only 10 years. Then the use of an incinerator was considered which would increase the life of the landfill for the residue to about 30 years. This method was then agreed on and bids were invited. The VKW walzenrost (roller grate) system was selected because other examples in Germany showed effective burnout, low maintenance rates, and high availability. Construction began in October, 1971. Because of the well established technology for flue-dust removal from combustion gases which have been partially cooled by heat-recovery boilers, this technique was adopted.

In April, 1972, construction was halted because of the new Federal requirement that flue-gas scrubbers should be incorporated to control the emissions of chlorides and fluorides. Construction resumed 10 months later and the plant was completed in September, 1975. Operation began in January, 1976. Industrial waste from both communities was first accepted at the plant on February 16, 1976.(1)

There was some minor local objection to the siting of the plant near the top of a deep valley adjacent to a community swimming pool. However, this did not affect plant plans. Composting had been briefly considered but because of the proportion of inorganic industrial waste expected, this alternative was not pursued.

The Plant Manager is Dipl. - Ing. Edgar Buchholz. The Assistant Plant Manager and Chief Engineer, Mr. Sedat Temelli, began work at this plant while it was still under construction in 1974. His prior experience was with the Duer boiler manufacturing company- now a part of Babcock Werke.

The cost of the plant was borne in the amount of 75 percent by Wuppertal and 25 percent by Remscheid.

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(1) See References, page 41.

REFUSE-FIRED STEAM GENERATOR EQUIPMENT

Figure 4-3 shows a map of the Wuppertal plant. Figure 4-4 shows a cross-section of the plant.

This plant is not yet up to full capacity for reasons that will be explained later. At the moment, the plant receives about 227,760 tonnes/yr (250,536 tons/yr), which is weighed on either one of two scales. A separate scale is used to weigh the residue which is trucked away. The scales were reliable for the first 3 months, then the electronic system became faulty.

The lower heat value of the waste received is estimated to range from 900 to 2600 Kcal/kg (1620 to 4680 Btu/lb) with an average in the range of 2200 to 2300 Kcal/kg (3960 to 4140 Btu/lb) [9210 to 9630 KJ/kg]. The waste is about one-third industrial and two-thirds residential.

They are negotiating with the neighboring towns of Solingen and Mettman to obtain more waste.

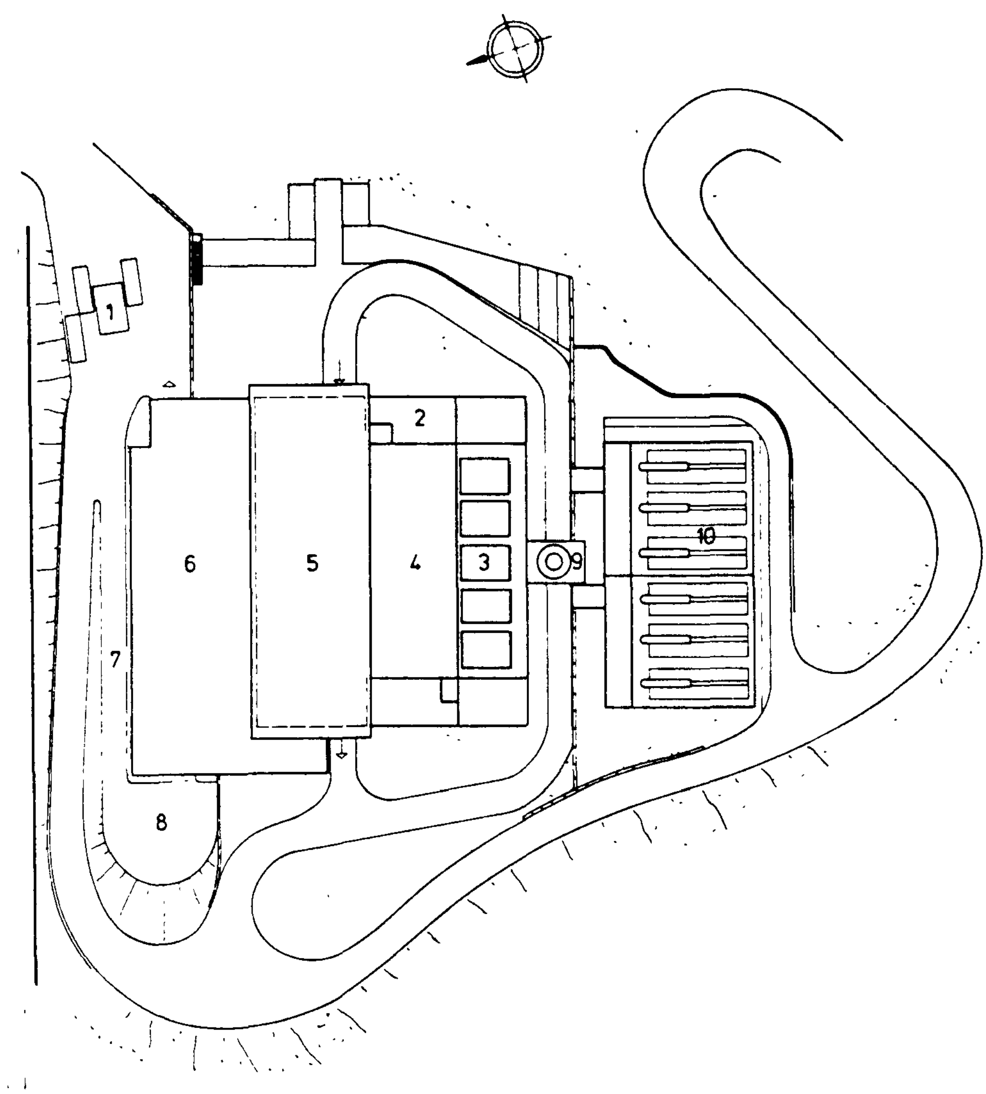
Where the scale operator observes bulk refuse in a truck, the driver is instructed to deliver it to a Lindemann shear adjacent to the pit. This shear operates from 7:00 a.m. to 4:00 p.m. With no storage location for bulky wastes, trucks must, at times, wait until the shear is free. A new storage bunker is planned. There are 2 shear operators, one of whom does cleaning and maintenance work from 2:00 p.m. to 4:00 p.m.

The nominal capacity of the shear at 1 tonne per 20 m^3 density is approximately 150 m^3/hr of normal bulky refuse. From the shear, the cut refuse flows by gravity into the pit.

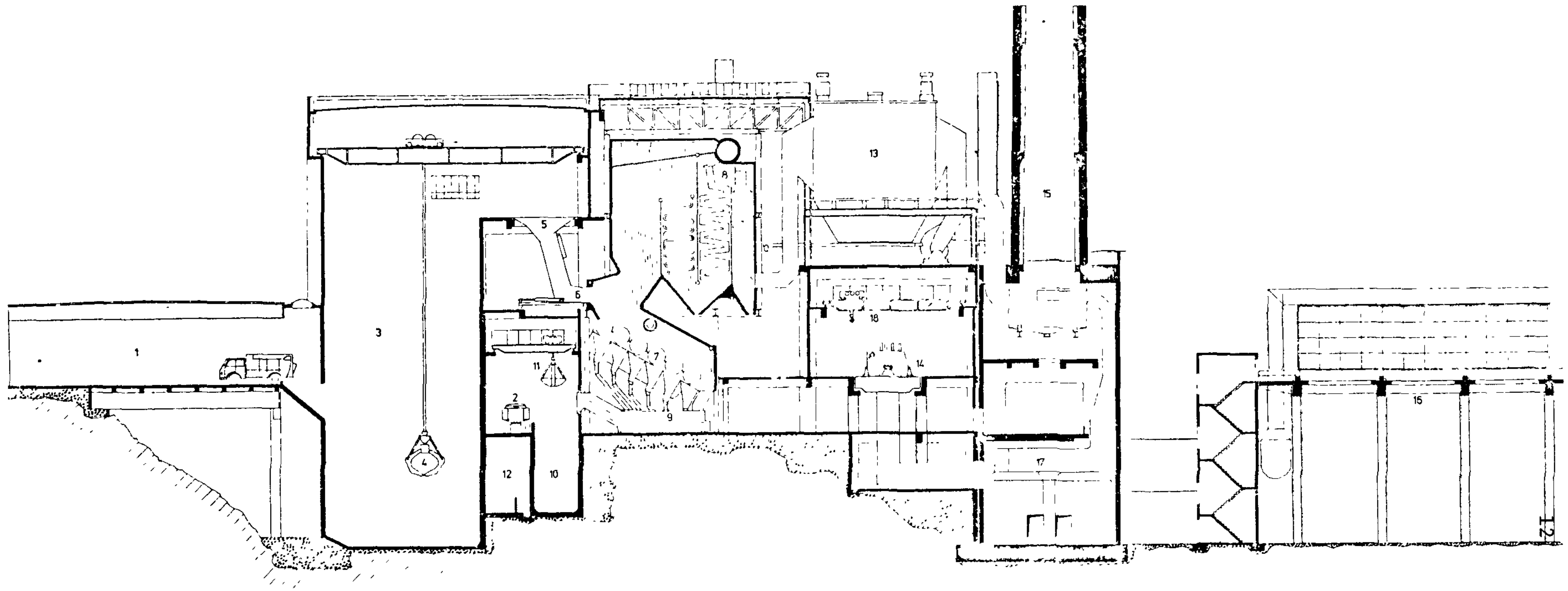
The refuse pit has a level-full capacity of 10,000 m^3 (353,100 ft^3 or 13,078 yd^3). The estimated maximum piled up capacity is approximately 18,000 m^3 (63,558 ft^3 or 23,540 yd^3). At a compressed and settled density of 645 lb/yd^3 (0.462 $tonnes/m^3$), this represents a maximum storage volume of 8316 tonnes (9148 tons), about 7-1/2 days' supply based on three-unit operation with the unit held as spare.

There are two Ridinger cranes (no longer being manufactured) of 10 tonnes each. There are two control cab locations, one on either wall of the pit. But only one cab and one crane are now in use; hence, there is one operator per shift plus a reserve operator.

FIGURE 4-3. MAP OF WUPPERTAL PLANT



1. Weigh station
2. Conference room
3. Machine shop and electrostatic precipitator
4. Boiler room
5. Refuse bunker
6. Tipping floor and bulky waste shear
7. Entrance ramp
8. Turning apron
9. Chimney
10. Air-cooled condenser



1. Tipping floor
2. Ash removal clock
3. Refuse bunker
4. Refuse crane bucket
5. Refuse feed hopper
6. Refuse feed throat
7. Roller grate, "Duesseldorf Type"
8. Steam generator
9. Residue conveyor
10. Residue bunker
11. Residue crane and bucket
12. Storage
13. Electrostatic precipitator
14. Turbogenerator
15. Chimney
16. Air-cooled condenser
17. Flue gas washer
18. Generator-room crane

(Courtesy Mullverbrennungsanlage Wuppertal GMBH)

FIGURE 4-4. CROSS-SECTION OF WUPPERTAL PLANT

The polyp-type crane buckets lift approximately 6 m^3 (7.8 yd^3). Replacement polyps will have a capacity of 7 m^3 (9.2 yd^3).

The crane operator can remotely control one of two water nozzles from each control cab for supression of pit fires. These have not been needed to date.

To provide an approximate measure of refuse fired, there are four pressure transducers on the bucket with digital readout and recording in the cab. The totals are tabulated for each shift.

After the crane operator loads a bucket and selects a desired hopper, the crane travel to a position above that hopper is automatic but the operator must then press the unloading button.

The polyp is serviced once per month. The crane cables are rotated every 3 months and they last 6 months.

Furnace Hopper and Feeder

The top of the four furnace hoppers are each 5 by 5 m (16.3 by 5.7 ft) in cross section. Water cooling of the chutes is available in the lower part but is used only when the temperature becomes too high. A lifting type of damper can close off the chute if burnback occurs.

Each stoker has an automatic hydraulic ram-driven feeder which can be controlled from the control room. Normally it strokes 15 times per hour. The length of stroke can be varied from 20 to 50 cm (5 to 12 in) by adjustment at the feeder. So far the feeders have had no problems. On some occasions, during initial operation, there was back-burning in the chute caused by loosely packed wood waste which allowed the flames to move upward in the chute. The solution has been for the crane operator to mix the refuse and to charge the hoppers in such a way that the chutes are kept packed full. Repeatedly, here it was emphasized that the most important worker in the plant is the crane operator.

Burning Grate

Figure 4-5 shows the "walzenrost" (roller grate) which was developed beginning in 1961 at the Flingern Power Plant, in Duesseldorf, using a four-roller pilot grate applied to an old formerly coal-burning furnace. 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. 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, exposing new burning surface and allowing for a continual redistribution of the 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 it iw operating.

Each grate roll is formed of ten sections, each of which contains 60 curved grate bars. The consoles at both sides above the rollers are cast of chrome-nickel alloy to resist abrasion. All grate bars are cast iron. There are six rolls per furnace at Wuppertal.

The gap between adjacent rolls is filled by a cast iron wiper bar spaced about 5 to 10 mm from the adjacent roll. This bar is strong enough to shear off refuse in the gap.

Normal wear of the seal gradually widens the gap which allows larger and larger pieces of refuse to fall through. Therefore the wiper seals are readjusted approximately three times a year. A screw conveyor removes the residue from underneath the grate. This area is inspected once per week and cleaned every four to six months.

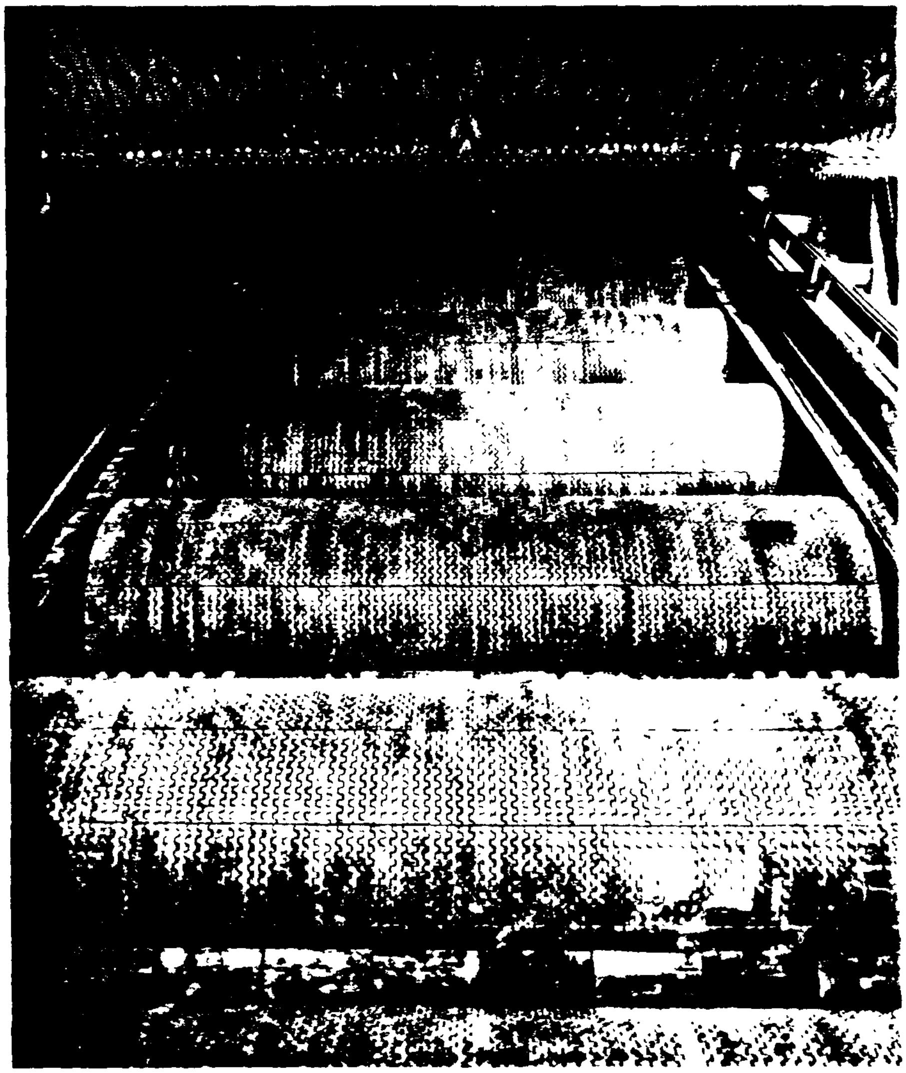


FIGURE 4-5. SIX DRUM WALZENROST (ROLLER GRATE); ALSO COMMONLY KNOWN AS THE DUESSELDORF GRATE. NOTE THE CAST IRON WIPER SEALS BETWEEN ADJACENT ROLLS WHICH PREVENT LARGE PIECES OF REFUSE FROM FALLING OUT OF THE FURNACE (Courtesy of Vereinigte Kesselwerke)

The roller shafts are hollow steel. Asbestos air seals at each end of the shaft require replacement every five or six years. Each roller constitutes a separate supply zone for primary air. The air enters the interior of the roll from both ends and from underneath 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 fule bed thickness approximately uniform. Mr. Karl Meier of VKW has provided the following information:

> "In our older roller cage construction - in a part of the combustion zone (rollers 2 and 3) - melted light metals, together with siftings, through the self-cleaning effect of the grate bars, entered the grate cages and were not removed laterally in one complete revolution. This occurrence is avoided in our new construction. Our current roller grate design heat release rates are for grates which are essentially wider, which therefore permits higher firing rates, and these are planned for all United States projects. These firing rates are used in the refuse burning plant at Wuppertal, which has been in trouble-free operation since 1975."

Startup is by means of No. 2 fuel oil fired in two sidewall burners to attain furnace outlet temperature of 800 C (1472F) required by German law before refuse can be fired.

Furnace Wall (Combustion and First Pass Radiation Chambers)

These four furnaces are thoroughly water cooled in accordance with the design and operating experience accumulated by VKW and its customers at the Duesseldorf plant and various other plants. The 57 mm (2.3 in) wall tubes are made of ST 35.8I steel, 4 mm (0.157-inch thick), and by means of welded fins they form a continuous membrane wall.

At the lower part of the combustion chamber, adjacent to the roller grate, pre-cast carbofrax blocks are used.

To protect the wall tubes of the combustion chamber from attack by high temperature flame impingement, they are studded and then covered with silicon carbide. Initially, part of the coating is 50% SiC and another part uses 80% SiC. For purposes of observation, the amount and type of each coating varies in each furnace. They consider this an experiment to observe which meets their conditions best. Later they will settle on the type and arrangement which performs best for future use when any replacements are needed.

As an extension of the protection afforded by the SiC, the same coating is carried upward along the walls of the radiation chamber for two or three meters (6.5 to 9.8 ft). The heating surface of the combustion chamber plus the coated and uncoated radiation chamber is stated by the manufacturer to be 775 m^2 (8331 ft^2). Other surfaces in each of the four steam generating systems are stated to be as follows:

Superheater	260 m^2	(2795 ft^2)
Convection tradition section	1734 m^2	(8665 ft^2)
Economizer	640 m^2	(6889 ft^2)
Total	2634 m^2	(28349 ft^2)

Water-washing of the boiler heating surfaces is partially used periodically for cleaning. There has been no slag buildup anywhere in the system. Hence, only fine ash deposits need to be cleaned off. Some other waste-burning furnaces might require periodic cleaning of heavy deposits of fused ash and slag that adheres strongly to the sidewalls of the combustion chamber.

As has been pointed out earlier, because of the fact that the flue-gas scrubbing system is not yet operational at Wuppertal, only two furnaces are operated at a time so as to limit the discharge of acid gases to the atmosphere. Thus, since the beginning of plant operation in January, 1976, and up to the time of our visit, May 20 and 26, 1977, or during an elapsed time of about 11,000 hours, each of the four boilers has operated only about 4000 to 5000 hours. While the intermittency of operation would not preclude excessively intense operation of each boiler during brief periods, the practical matter is that alternate means had obviously, already previously been employed for disposal of the 525,600 tonne/yr. which is the theoretical full time capacity of all four units potentially now available. Hence, with the two-unit operation now in practice which burned in 1976, a total of about 178,000 tonnes, the alternate disposal facility probably has been operated less intensively than it was before this MVA was built. Thus, there is as yet no great need nor perhaps much pressure from any quarter to operate the MVA units more intensively. (Actually, as designed, this plant was intended to operate only three boilers at a time, leaving the fourth unit for maintenance and standby).

From Mr. Temelli's previous experience in the boiler industry he indicated that he is fully aware of the multiple problems of corrosion, erosion, and frequent maintenance requirements of combustion and thermal equipment when it is severely overloaded. He explained that because of the variable nature of refuse, if the nominal load per furnace is 15 tonnes per hour (16.5 tons/hr), peaks will be encountered of 18-19 tonnes per hour. To avoid the added maintenance resulting from such peaks, these units are now operated at an average rate of 13 tonnes per hour (14.3 tons/hr) or about 13 percent under rating. Since there is no immediate need to more fully load these units, they will probably continue to be operated conservatively.

So far there has been no tube corrosion observed after nearly 6000 hours operation of each unit. They are designed to deliver steam at the rate of 46,000 kg/hr (101,200 lb/hr) [50.6 tons/hr] at a temperature of 350 C (662 F) and 28 bar [392 psig] absolute.

Heat Release Rate

Heat release rates are as follows. The grate area is 43.74 m^2 (535.4 ft^2), corresponding to a grate width of 3.5 m (11.48 ft). The total furnace volume up to the throat where the gases enter the radiation chamber is 158 m^3 (5580 ft^3). Since the walls of the radiation chamber are, to a large extent, studded and coated with various compositions of silicon carbide, it is evident that, as in most similar plants, the designers did not expect the burning to be completed in the main furnace. Accordingly, for the purpose of estimating volume heat release rate, half of the height of the radiation chamber up to the beginning of the turn of the gases toward the superheater has been assumed to serve as combustion volume; that is, one half of 117 m^3 (4132 ft^3) or 58.5 m^3 (2066 ft^3) is added to the estimated furnace volume of 158 m^3 (5580 ft^3) for a total assumed, active, combustion volume of 276.5 m^3 (7646 ft^3).

Table 4-1 shows the resulting estimated dimensions and rates.

The grate burning and heat release rates seem moderately high. The estimated volume release rate is conservative. The lack of slag adhesion to the furnace walls in significant quantities is a result of the refuse composition. Also, the relatively high excess air used coupled with the excellent cooling effect of the relatively large furnaces could be important.

Excess Air

It is Mr. Temelli's practice to operate with a furnace exit gas composition of nine to eleven percent oxygen to avoid formation of CO. He feels that if O_2 were to drop to seven percent and lower, CO would form in appreciable quantities which might increase the danger of chloride corrosion. While recognizing that high excess air reduces boiler efficiency, the preference at this plant is "long life rather than optimum performance". This is a common although not universal policy among many operators of waste to energy plants in Europe. A few still strive to find practical ways to increase energy-recovery efficiency without increasing boiler-furnace maintenance costs--thus maximum steam temperature and minimum practical excess air are still sought in some plants. However, the inherent variability of refuse as a fuel means that the optimum conditions may frequently be unavoidably exceeded, hence prudence would dictate that the trend toward conditions of maximum efficiency should be cautious steps.

Superheater

As shown in Figure 4-4 when the gases reach the top of the radiation chamber, which constitutes the first pass, they turn through 180° at moderate

TABLE 4-1. ESTIMATED BURNING VOLUME DIMENSIONS AND HEAT RELEASE RATES FOR EACH OF THE FOUR WUPPERTAL FURNACES

Grate area	49.74	m^2
Grate area	535.4	ft^2
Furnace volume	158	m^3
Furnace volume	5580	ft^3
Radiation chamber volume	117	m^3
Radiation chamber volume	4132	ft^3
Furnace plus 1/2 rad. ch. vol.	216.5	m^3
Furnace plus 1/2 rad. ch. vol.	7646	ft^3
Lower heating value	2250	kcal/kg

	Design Rate	Rate as Now Operated
Total daily firing rate tonnes/day	360	312
Total daily firing rate tonnes/hr	15	13
Firing rate per boiler tons/hr	16.5	14.3
Grate burning rate Kg/m^2-hr	302	267
Grate burning rate lb/ft^2-hr	62	54.7
Grate heat release rate $kcal/m^2$-hr	678,500	588,000
Grate heat release rate MJ/m^2-hr	2,841	2,462
Grate heat release rate Btu/ft^2-hr	250,160	216,780
Volume heat release rate $kcal/m^3$-hr	155,890	135,704
Volume heat release rate MJ/m^3-hr	653	566
Volume heat release rate Btu/ft^3-hr	17,520	15,180

velocity and flow downward through the superheater sections which consist of two banks in series of horizontal tubes installed in a sinuous manner. The nine rows of tubes in the first section are formed of carbon steel designated ST. 35.8 II. The last two rows in the second section are formed of alloy steel designated 15 mo 31. This is the point of maximum steam temperature. Their outside diameter is 51 mm (2.0 in) and wall thickness is 4 mm (0.152 in). The tubes are not staggered in the gas flow but are in-line with the center lines of the rows 225 mm (8.8 in) apart. The superheater is cleaned by steam blowers which initially operated at 15 bar (15.3 kg/cm^2) [218 psig]. However, because of well-known experiences elsewhere with the high velocity of steam blowers having a cutting or erosive action on adjacent tubes, these blowers are now operated at a reduced pressure of 10 bar (10.2 kg/cm^2) [145 psia]. Also, the tubes likely to be eroded by the steam are covered on the exposed side by 6-mm thick (0.24 in) half-round steel shields made of Sicromal. So far the shields tried of Sicromal eight and nine did not last long. Sicromal 10 seems to be better. Table 4- 2 shows the composition and properties of Sicromal.

The estimatea gas temperature leaving the furnace radiation section is 830 C (1526 F). As the gas enters the superheater it has cooled to about 720 C (1328 F).

The unobstructed cross-sectional dimensions of the radiation pass are 3.805 m wide by 4.475 m deep (12.5 by 14.7 ft). Of the superheater pass, the corresponding dimensions are 3.805 m wide by 3.337 m deep (12.5 by 10.8 ft).

Superheat temperature control is provided by a spray-type attemperator between the two sections. Attemperators are spray devices that inject pure demineralized water into the steam flow so that steam temperature can be controlled to plus and minus 5° C. Maximum steam temperature ahead of the attemperator is estimated to be 420 C (788 F).

It has been observed that the presence of cross-over pipes near the top of the superheater form a "shadow" of dust deposition on the superheater about 152 mm to 200 mm (6-8 in) deep. If the gas temperature at that point increases, that deposit becomes hard.

TABLE 4-2. COMPOSITION OF SICROMAL STEEL USED FOR SHIELDING TUBES FROM HOT CORROSIVE GASES

Designation	Manufacturer	C %	Si %	Cr %	Al %	S %	Tensile Strength at 20 C psi	Tensile Strength at 20 C MPa	Tensile Strength at 800 C psi	Tensile Strength at 800 C MPa	Yield Strength at 20 C psi	Yield Strength at 20 C MPa	Yield Strength at 800 C psi	Yield Strength at 800 C MPa	Elongation at 20 C %	Elongation at 800 C %	Reduction in Area at 20 C %	Reduction in Area at 500 C %	Common Uses
Sicromal 8	Vereinigte Stahlwerke, Duesseldorf	0.12 (max)	0.8	4-5	0.5	--	67,000	462	10,000	69	43,000	296	6,000	41	20	38	75	93	Superheater tubes, recuperator tubes.
Sicromal 9	"	0.12 (max)	1.2	13	1.0	0.005 (max)	78,400	541	11,400	79	40,000	276	7,200	50	15	50	68	90	Superheater and recuperator tubes, pipes, fittings.
Sicromal 10	"	0.12 (max)	1.0	18	1.0	0.005 (max)	85,200	587	14,500	100	50,400	347	7,200	50	10	53	63	98	Pyrometer tubes, anchor bolts, furnace parts.

Source: from Woldman - "Engineering Alloys"

Boiler (Convection Section)

As the gases flow downward from the bottom of the superheater they are again turned through an angle of 180° and flow upward through the boiler convection section. The unobstructed cross-sectional dimensions of this pass are 3.805 m wide by 3.150 m deep (12.5 by 10.3 ft). The sinuous tubes are made of 35.8 I steel and are 57 mm in diameter with 4 mm wall (2.2 in, 0.157 in). The centerline spacing of the in-line tubes is 150 mm (5.9 in). Those tubes nearest the soot blowers are protected by Sicromal shields in the same way as described earlier for the superheater.

Economizer

As shown in Figure 4-4 the gas flow is downward through the economizer. The tubes are also 35.8 I steel, 38 mm in diameter (1.5 in) with 3.6 mm wall (0.14 in). The in-line rows are spaced 110 mm (4.3 in) on centers. The gas temperature leaving is about 220-240 C (428-464 F).

Boiler Water Treatment

Water treatment is provided by the usual deionizing and deaerating equipment.

Primary Air Supply

The primary air is drawn from near the top of the refuse bunker to provide a positive inward flow of fresh air to the bunker area. Each furnace has a separate radial blower made by Buettner-Schilde-Haas of the Babcock group. Each can supply up to 100,000 Nm^3/hr (58,860 scfm) at 140 mm water static pressure (5.5 in). The supply of air to each of the six grate rollers is controlled by a manual damper. A record is made every 1/4 hour of each damper setting. So far, there have been no problems with the primary air system.

Perhaps because the operation of only two boilers at a time at moderate rate, the rate of primary air induced to flow through the bunker has been too low to prevent vapor accumulation at times and annoying condensation on all surfaces in the bunker area. To alleviate this, separate exhaust ventilating fans are used.

Secondary Air

One radial blower for each furnace takes air from near the top of the boiler room at a rate of 5.5 m^3/sec (20,000 Nm^3/hr) [11,650 scfm]. The available air pressure is 800 mm water static (31 in). This air is supplied to a total of 60 overfire air jets which are 50 mm in diameter (2 in). There are two rows of jets close together in the front wall, and two more rows in the forward portion of the slanting rear wall. All of these jets are directed downward at an angle. The front wall jets are just below the nose of the front wall shown in Figure 4-4 so that their downward direction provides somewhat opposed mixing to the burning gases rising upward out of the furnace. The rear wall jets are just below the nose of the rear wall and are directed slightly downward into the initial burning zone of the furnace.

Actual secondary air flow ranges from 12,000 to 14,000 Nm^3/hr (7,000 to 8200 scfm). Normally the dampers controlling secondary air are not changed. Mr. Temelli explained that certain other plants also had tertiary air jets positioned half way up in the radiation chamber to try to combat tube corrosion near the top of that chamber but that at this plant, because of the relatively modest steam temperature, 233 C saturated (451 F) at 28.4 bar (403 psig) and 350 C (662 F) superheated, tertiary air was not believed to be necessary.

Energy Utilization Equipment

The only use of the steam generated is to make electricity in two turbo-generators capable of producing 20 mw each. Maximum steam consumption of each is 107 tonnes/hr (235,700 lb/hr). Specific design steam consumption is 5.35 kg/kw-hr (11.8 lb/kw-hr). Exhaust to air-cooled condensers is 0.12 bar (0.12 kg/cm^2) [1.7 psig]. The output is supplied at 10,000 volts to the city electrical system.

The condensate returns from the condenser at an average temperature of 52 C (126 F). In order to heat it to 110 C (230 F) before returning it to the boiler, it is mixed with about 10 t/h (22,000 lb/hr) of steam extracted from the turbines.

POLLUTION CONTROL EQUIPMENT

The pollution control equipment at this plant is unique in that the four conventional electrostatic precipitators are followed by two scrubbers to remove most of the HCl and HF emitted. At the time of the plant visit, May 1977, the scrubber system was still under construction, hence, no data are available on scrubber performance. The performance criteria is that emission of HCl shall not exceed 100 mg/Nm^3 corrected to 7% CO_2. The ducting is arranged so that when, as normal, three units are burning, the gases from only two will pass through the scrubbers. The unscrubbed hot gases will then be mixed with the cool, scrubbed gases, about 60 C (140 F), for purposes of reheat to about 200 C (390 F) to augment exhaust plume buoyancy and invisibility.

Precipitator

The four electrostatic precipitators were manufactured by Buettner-Schilde-Haas under license from Svenska Flaktfabriken. They are 7.95 m high, 7.15 m wide, and 10.2 m deep (26 x 23 x 33 ft). Table 4- 3 shows the precipitator design characteristics. Construction was not preceded by a flow model investigation. No performance data were available at the time of the visit, May 1977.

At first there was some problem with ash buildup in the fly-ash hoppers but an increased slope of the hopper sides eliminated that problem.

Induced Draft Fan

Initially, there was some problem from vibration of the induced draft fans caused by dust deposits on the blades. Improved control of burning appears to have eliminated that problem.

TABLE 4-3. PRECIPITATOR CHARACTERISTICS

	SI units	ENG. units
Gas flow rate	100,000 Nm^3/h	58,860 scfm
Maximum gas temperature	290 C	554 F
Clean gas conditions (at 220C [428 F] and 11% 0^2)	100 mg/Nm^3	0.044 gr/scf
Number of fields	2	2
Projected collecting surface	2,810 m^2	30,230 ft^2
Residence time	7.0 sec	7.0 sec
Particle drift velocity	8.24 cm/s	0.23 f/s
Free gas flow area	48.8 m^2	525 ft^2
Gas flow velocity	1.03 m/s	3.4 f/s
Number of power packs	2	2
Input power	380 V/50 hz	380 V/50 hz
Operating voltage	45 KV	45 KV
Power	46 KVA	46 KVA
Current	600 mA	600 mA
Power consumption	27.6 kw	27.6 kw
Hopper heaters (2)	220 V/8 kw	220 V/8 kw

Source: Courtesy of Vereinigte Kesselwerke.

Stack Construction

The single masonry chimney, 100 m (328 ft) high, is built of ceramic block known as Asplit O. The top 15 m (50 ft) is built of less expensive Asplit CN.

The chimney was designed with a top inside diameter of 3.3 m (10.8 ft) but until the fifth boiler is installed, a ceramic block nozzle has been built inside the stack top to reduce the exit diameter to 2.7 m (8.9 ft). This constitutes an area reduction of 33 percent which, for the expected three-unit operation in the immediate future, will provide the same exit velocity and plume rise as the expected later four-unit operation after a fifth and final unit becomes available as standby. As seen in Figure 4- 6 the top of the chimney is painted black to cope with any staining that may occur.

Solid Residues

The grate residue and collected flyash drop into a quench tank from which the wet solids are carried out by a platen type ash extractor system to the ash bunker. From there a crane lifts the residues to trucks which deliver them to a private processing firm immediately below the plant. Part of this operation is shown in Figure 4- 7 . The private operator pays DM 1.50 per tonne ($0.60/ton) of residue. In this outdoor cleaning and sizing operation the residue is upgraded to a useful raw material which apparently is in much demand.

Wastewater Discharge

The principal waste water leaving the plant is that carried down the hill in the quenched residue.

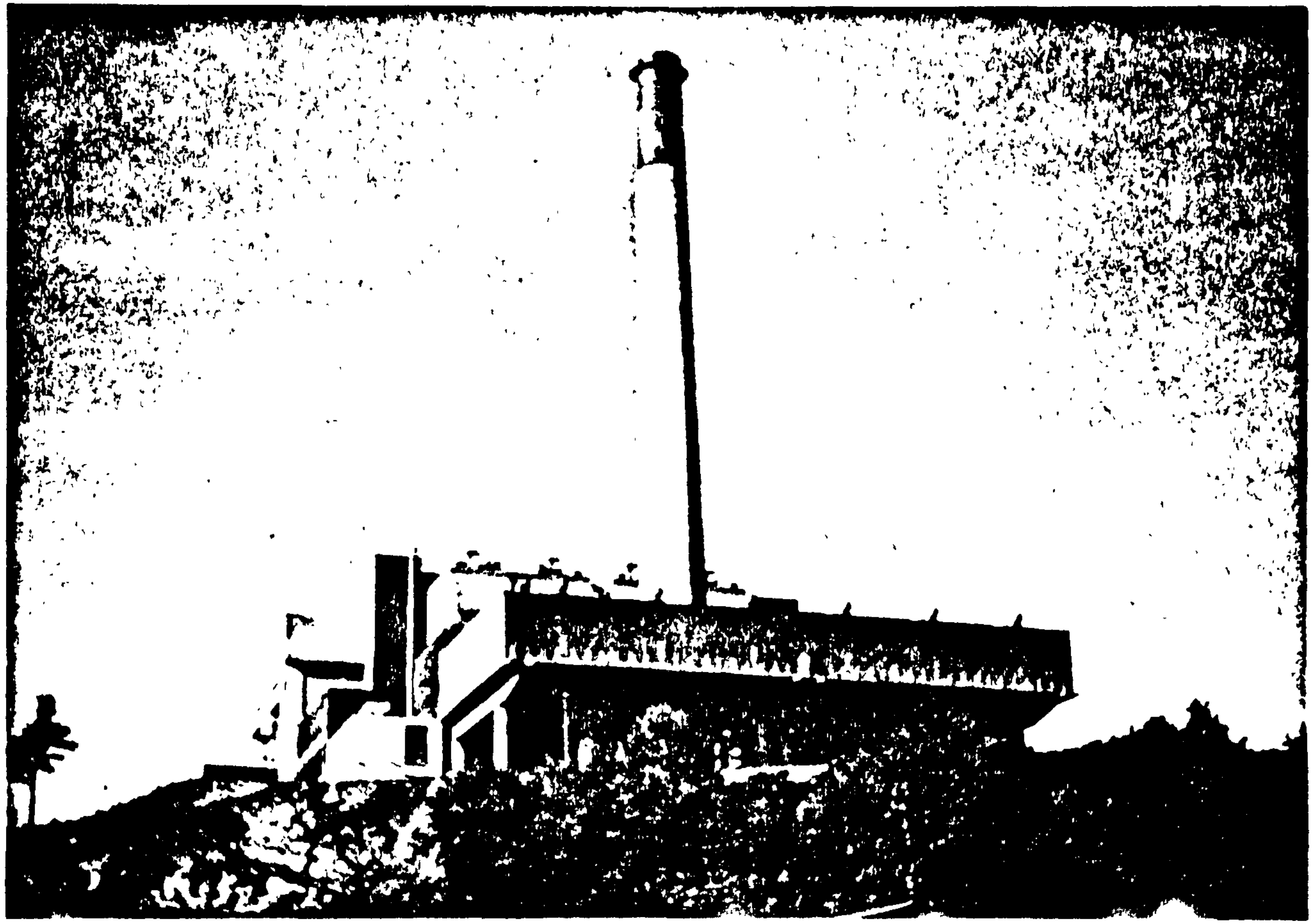


FIGURE 4-6. UNDERSIDE VIEW OF WUPPERTAL PLANT HIGHLIGHTING THE AIR-COOLED STEAM CONDENSERS AND THE STACK (Battelle Photograph)

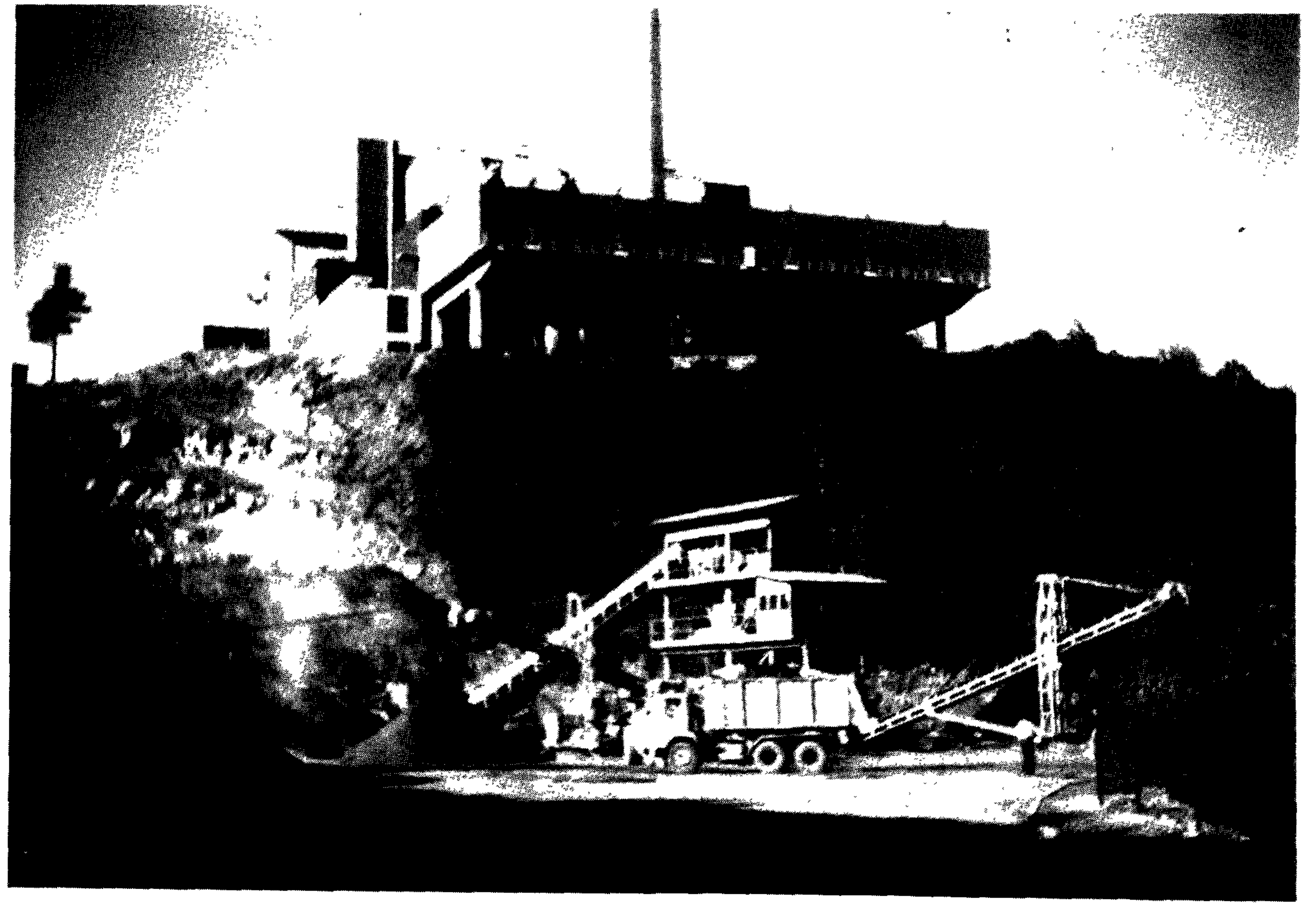


FIGURE 4-7. WUPPERTAL PLANT SHOWING, IN TOP PORTION, THE AIR-COOLED STEAM CONDENSER HOUSING AT REAR OF PLANT AND BELOW THE PRIVATELY-OPERATED RESIDUE PROCESSING PLANT (Battelle Photograph)

POLLUTION CONTROL ASSESSMENT

At the time of the visit the scrubbers were not yet completed and the precipitators had not been tested. The appearance of the stack plume and plant was extremely clean and attractive.

A striking and very unique indication of the need to keep this plant clean is that a public swimming pool is within clear sight of the plant in the narrow valley below. Figure 4- 8 , showing the pool, was photographed from the plant conference room window. The distance from the plant property to the pool is about 120 m (400 ft).

Noises

The new Federal regulation on noise near an industrial facility limits it to 35 dba. With two units operating, this plant is close to that limit. Accordingly, it is expected that sound absorbent louvers will need to be installed beneath the condenser which was purposely built in the elevated position shown in the previous Figure 4-7 to allow space for installation of sound absorbent surfaces.

FIGURE 4-8. DOWNWARD VIEW FROM THE WUPPERTAL PLANT SHOWING THE NEARBY COUNTRY CLUB AND SWIMMING POOL (Battelle Photograph)

PERSONNEL AND MANAGEMENT

Figure 4- 9 shows the organization chart for the Wuppertal plant.

The plant operates 24 hours per day, three shifts, seven days per week. The individual work-week is 40 hours.

There are 100 employees. The average shift workers are paid DM 25,000/yr including fringe benefits ($11,000/yr at DM 2.27/$). The total annual payroll is DM 37 x 10^6 ($16.28 x 10^6).

The commercial manager and supervisor have additional off-site duties with the Wuppertal City Administration. Mr. Masanek is also responsible for Wuppertal's Transportation Department. Mr. Hilkes only works for the plant 60% of his time.

Data processing is done on a Niksdorf System 8000 located at the plant.

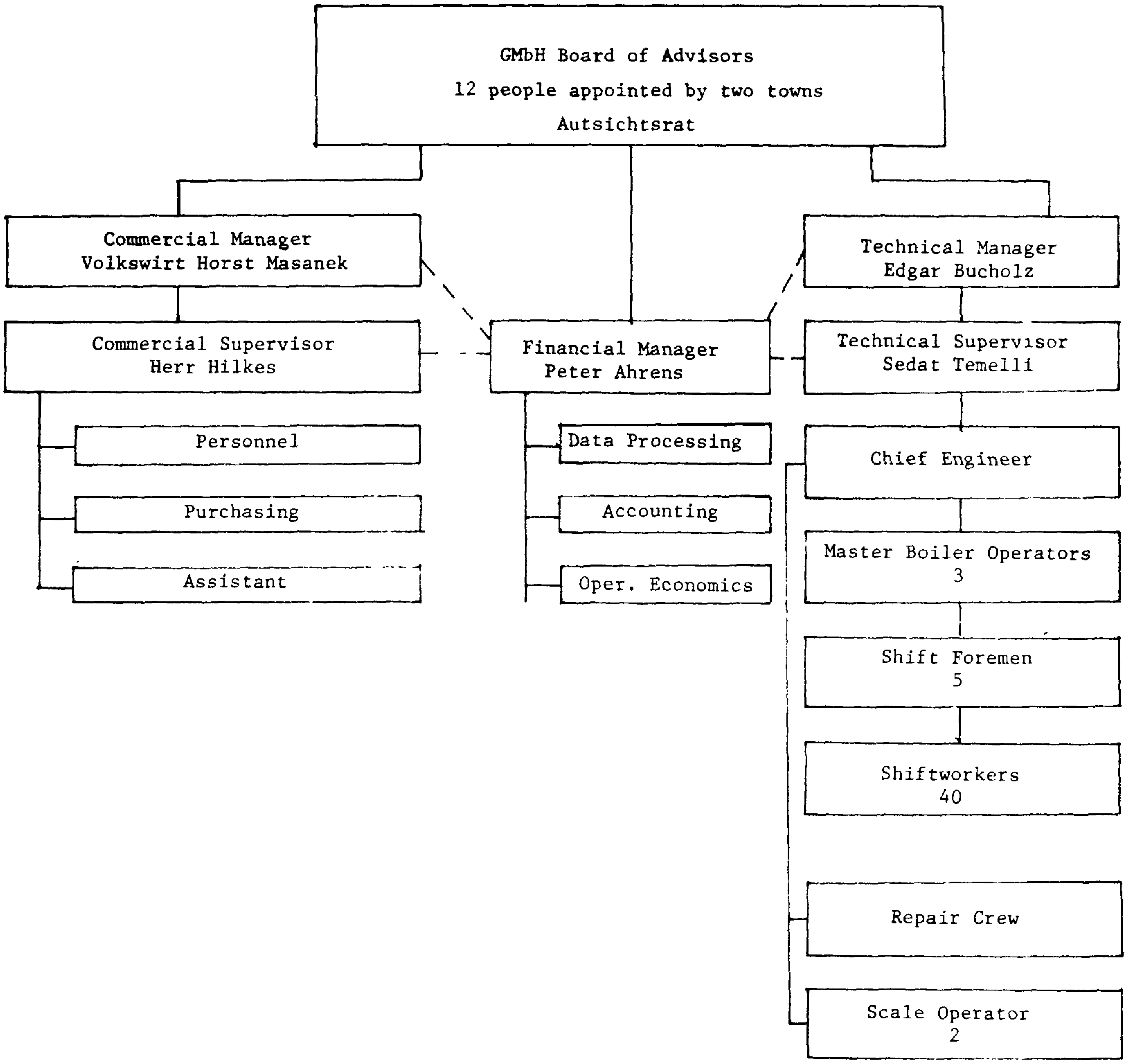


FIGURE 4- 9. WUPPERTAL ORGANIZATION CHART

ENERGY MARKETING

The only energy sold from this plant is electricity which is sold to the local public power network at a price ranging from 2.6 pf to 4.9 pf/kw-hr ($0.011 to $0.022 per kw-hr).

ECONOMICS

Capital Investment

The plant cost DM 126 x 10^6 in 1975 (\$51.2 x 10^6 at DM 2.46/\$). This was financed as follows:

	Millions of 1975 DM	Millions of 1975 \$
State Grant (N. Rhein - Westphalia)	24	9.7
7.5%, 18-yr loan, Municipal Savings Bank	40	16.3
6%, 18-yr loan, Federal Bank	20	8.1
7%, 4-yr loan, Vereinigte Kesselwerke	12	4.9
Commercial loan to be arranged for scrubbers	12	4.9
Commercial loan for final payment to VKW	12	4.9
Prefinancing from cities of Wuppertal, Remscheid	6	2.4
Total	126	51.2

The column of dollar costs was calculated using an exchange rate of DM 2.46/\$.

Table 4-4 shows the distribution of construction and equipment expenditures up to December 31, 1975, when the plant was nearly completed but not yet operational. Construction work on the scrubber system was still underway during the plant visit in May 1977. The currency conversion used in Table 4- 4 was the mid-1977 rate of DM 2.27/\$ about the time of the visit.

The land was previously owned by the city and is valued at DM 10 x 10^6 (\$4.1 x 10^6).

Operating Costs

Because the plant is still under construction in the scrubber area and is therefore operating on a reduced schedule of only half of full capacity, costs are not yet well established. The estimated cost for 1976 was DM 79.80/tonne (\$32/ton) after credits are taken for sale of the residue and electricity.

TABLE 4-4. STATUS OF CONSTRUCTION EXPENDITURES-
WUPPERTAL - AS OF DECEMBER 31, 1975

	Deutsch Marks	Thousands of Dollars at DM 2.27/$
Buildings, structures	530,678.82	233
Planning -- Kesselwerke	1,196,223.05	526
Main contract with Vereinigte	54,400,000.00	23,980
Advance payments to Vereinigte	1,007,121.20	443
Excavation - foundation	2,154,521.80	948
Turbine I - 1.5 km	2,686,816.17	1,182
Transformer - power line	3,305,595.40	1,454
Feedwater tank	149,109.73	66
Residue crane	236,991.87	104
Weigh scale	937,780.18	413
Offices, office equipment	240,379.49	106
Supporting walls (required on hillside site)	2,521,616.57	109
Scrubbers	4,619,810.24	2,033
Miscellaneous	123,613.24	54
Air-cooled condenser II	2,110,150.84	928
Turbine II	2,008,323.89	884
Landfill	84,120.65	37
Total Construction as of December 31, 1975	71,312,853.14	34,458
Construction Interest Payments		
Interest to Vereinigte Kesselwerke	5,240,600.00	2,306
Interest on other loans	2,289,121.68	1,007
Miscellaneous interest	233,336.72	103

TABLE 4. (Continued)

	Deutsch Marks	Thousands of Dollars at DM 2.27/$
Premiums	158,470.00	70
Sub-total	7,921,528.40	3,485
Total expenditures through December 31, 1975	86,234,381.54	37,943
Total estimated final cost of completed plant	126,000,000.00	55,440
Estimated final cost per daily tonne of capacity	87,500 (DM/tonne)	42,350 ($/ton)

Source: Translated from 1975 Financial Report of MVA Wuppertal GMBH, March 1977.

It is hoped that with the plant operating at nominal capacity in 1978, the cost will decrease to DM 65 or 70/tonne (826 or 28/ton).

They estimate a "fixed" operating cost regardless of throughput of DM 20 x 10^6 per year (\$8.8 x 10^6). This fixed portion would amount to DM 50/tonne (\$20/ton) if the expected three units ran at capacity 365 days per year.

Revenues

In 1976 the revenue from the sale of electricity was DM 3.5 x 10^6 (1.54 x 10^6 at DM 2.27/\$). Tipping fees totalled DM 16.5 x 10^6 (\$7.26 x 10^6). For an expected 220,000 tonne annual throughput, these totals translate to an income of DM 90.91/tonne (\$36.36/ton). However, the actual tonnage in 1976 was much less.

Each household served pays an annual fee of DM 230 for rental of a 110 ℓ (3.89 ft^3) container that is emptied once per week. Estimated expected public collection in Wuppertal was 110,000 tonnes in 1976 but actual public collection was only 94,000. Remscheid collected 16,000. Private haulers brought 68,000 for a grand total of only 178,000 tonnes (195,800 tons).

Income is DM 1.5/tonne (\$0.55/ton) of residue.

REFERENCES

(1) Financial or Business Report 1975, Refuse Burning Plant, Wuppertal GMBH, dated March, 1977.

(2) B. W. Westphal and H.G. Norbisrath, Müllverbrennungsanlage Wuppertal, Energie, Vol. 11, 1973.

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

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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

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

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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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