United States
Environmental Protection
Agency

Office of Water and
Waste Management
Washington, D.C. 20460

SW 176C.12
October 1979

Solid Waste

European Refuse Fired Energy Systems

Evaluation of Design Practices

Volume 12

Prepublication issue for EPA libraries
and State Solid Waste Management Agencies

EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

Copenhagen: Amager Denmark

This trip report (SW-176c.12) describes work performed for the Office of Solid Waste under contract no. 68-01-4376 and is reproduced as received from the contractor. The findings should be attributed to the contractor and not to the Office of Solid Waste.

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Volume 12

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

This report was prepared by Battelle Laboratories, Columbus, Ohio, under contract no. 68-01-4376.

An environmental protection publication (SW-176c.12) in the solid waste management series.

TRIP REPORT

on

COPENHAGEN: AMAGER, DENMARK

on the contract

EVALUATION OF EUROPEAN REFUSE-FIRED
ENERGY SYSTEM DESIGN PRACTICES

in October 3-6, 1977

to

U.S. ENVIRONMENTAL PROTECTION AGENCY

EPA Contract No. 68-01-4376
RFP No. WA-76-B146

by

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March 31, 1978

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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:

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Architect	J. Maglebye Architectural Office
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STATISTICAL SUMMARY

GENERAL	
Name of plant	Amager Plant
Location of plant	Copenhagen, Denmark
Year completed	1970
Administration/Ownership	Communities of interest consist of several municipalities including parts of Copenhagen
Area of plant	approx. 34,000 m^2
Area of building	approx. 19,000 m^2
Cost of construction, including a building	approx. 115,000,000 D.Kr.
Design Data	
Plant capacity	
Annually	220,000 - 330,000 tonnes/yr
Daily	864 tonnes/24 h
Capacity, each furnace	
Daily	288 tonnes/24 h
Design hourly	12 tonnes/hour
Actual hourly	13 tonnes/hour
Number of furnace	
Operating	3
Stand-by	0
Extension potential	3
Calorific value of refuse (design)	
Lowest (design)	1,000 kcal/kg
Average (design)	2,000 kcal/kg
Highest (design)	2,500 kcal/kg
Calorific value of refuse (actual)	1,800 kcal/kg

Composition of Refuse

	Lowest	Average	Highest
Combustibles	26%	45%	55%
Ash and inerts	42%	26%	22%
Water	32%	29%	23%

Furnace temperature	
Minimum	800 C
Average	950 C
Maximum	1,000 C
Contents of unburnt matter in residue	0 - 3%

OPERATION OF PLANT

Cost of operation and maintenance	D.Kr. 35/tonne of refuse
Number of operators and workers	45
Number of officers	10
Operating hours of plant	24 hours/day 7 days/week
Working hours of operators	8 hours/day 5 days/week
Number of shifts	5
Electric power consumption	1,000,000 KwH/month
Water consumption	
City water (excluding sea water) for clinker cooling	7,000 tonnes/month
Actual continuous operating time	approx. 12 weeks
Actual operating days	365 days/year
Maintenance and repair of plant	
Regular or periodical overhaul and repair including mechanic, electric, and boiler systems	normal

REFUSE COLLECTION AND TRANSPORTATION

Population in refuse collection region of the plant	550,000-600,000
Area of refuse collection of the plant	138 km^2
Amount of refuse collected, presently	1,400-1,000 tonnes/day
Disposal of refuse	
Incineration	50%

Dumping at sea	0%
Reclamation	0%
Other:/dump/ industrial refuse	50%
Method of transportation	Truck
Charge of collection	Charged 30 D.Kr./t.

REFUSE STORING

Weighing equipment of refuse	
Number	2
Type	Automatic
Capacity	50 tonnes
Recording, printing, and summation of weight	Automatic
Refuse silo (bunker)	
Number	1
Capacity	10,000 m^3
Dimension	
Length	48 m
Width	17 m
Depth	13 m
Specific weight of refuse	0.2-0.3 tonnes/m^3
Storing capacity	3 days max. refuse delivery
Refuse silo door	
Type	Flap, double-hinged
Number	11
Dimension	
Height	8.0 m
Width	3.8 m
Thickness, total	122 mm
Operation	Hydraulic
Capacity	10,000 m^3
Big refuse crusher	None

REFUSE FIRING PLANT

Furnace

Filling hopper

Number	1 per furnace
Clear opening at top	6 m x 6 m
Clear opening at bottom	2.3 m x 1.15 m
Height	6 m
Thickness of plate	8 mm
Materials	Mid steel
Volume	15 m^3
Filling chute	
Number	1
Clear opening	2.3/2.7 m x 1.15 m
Height	8.5 m
Thickness of plate	8 mm
Volume	19 m^3
Swivel gate in filling chute (damper)	
Number	1
Dimension	2.58 m x 1.26 m
Thickness	10 mm
Operation	Manual
Grate I	
Width of grate	2.7 m
Length of grate	2.5 m
Area	6.75 m^2
Velocity of grate	3 stroke/min.
Length of grate stroke	130 mm
Type of grate	Grate bar, grate plate
Materials of grate	
Grate frame	Meehanite HR
Grate bar or plate	Meehanite HR
Side seal	Nicromax
Grate II	
Width of grate	2.7 m
Length of grate	2.0 m
Area	5.4 m^2
Frequency of grate	3 stroke/min.
Length of grate stroke	130 mm
Type of grate	Grate bar

Materials of grate	
Grate frame	Meehanite HR
Grate III	
Width of grate	2.7 m
Length of grate	5.0 m
Area	13.5 m^2
Velocity of grate	3 stroke/min.
Length of grate stroke	130 mm
Type of grate	Grate bar, grate plate
Materials of grate	
Grate frame	Meehanite HR
Grate bar or plate	Meehanite HR
Side seal	Nicromax
Grate IV	None
Rotary kiln	
Shape	Cylindrical
Diameter	
Inside of shell	4 m
Inside of lining	3.4 m
Length	8 m
Volume	73 m^3
Number of revolutions	
Range	0 - 12 rph
Normal	6 - 8 rph
Inclination	3 deg.
Materials of shell	DIN 42.2 steel
Materials of support ring	High tensile strength steel castings
Materials of support roller	High tensile strength steel castings
Materials of thrust roller	High tensile strength steel castings
Number of support rings	2
Number of support rollers	2
Number of thrust rollers	1
Number of drive support rollers	2
Steps between grates	
Number of steps	2
Height of steps between Grate I	1.0 m

and Grate II			
Height of steps between Grate II and Grate III		2.0 m	
Steps beetween grate and rotary kiln			
Number of steps		1	
Height of step		1.0 m	
Width of steps		2.7 m	
Hopper under grate			
Number		4	
Thickness of plate		6 mm	
Size of chute		240 x 240 mm	
Clinker chute			
Clear opening (or 100 ?)		900 mm x 1,000 mm	
Height		1,900 mm	
After combustion chamber			
Volume		125 m^3	
Hydraulic equipment for grate movement and rotary kiln			
Number per furnace		1 set/furnace	
Hydraulic pump			
Number per furnace		Operating 2, standby 0	
Capacity		47 lit/min. each pump	
Pressure		70 kg/cm^2g	
Motor		15 HP each	
Oil tank		600 liters	
Hydraulic cylinder			
	Grate I	Grate II	Grate III
Number	5	5	5
Cylinder bore	80 mm	80 mm	85 mm
Cylinder stroke	130 mm	130 mm	130 mm
Hydraulic motor for rotary kiln			
Number per kiln		2	
Revolution		max. 1,200 rpm	
Torque		3 kg-m	
Speed reduction equipment			
Type		Double worm gear	

Number per kiln	2
Revolution	max. 76 rph
Torque	1,272 kg-m
Ratio of reduction	1:800

'ENTILATING AND DRAFTING PLANT

Primary air (P.D. Fan)	
Manufacturer	Nordisk Ventilator
Number per furnace	1
Amount of air	45,000 Nm^3/h
Static pressure	230 mmAq
Temperature	30 C
Number of revolutions	1,490 rpm
Drive type	Belt drive
Motor size	75 HP
Secondary air fan (cooling air fan)	
Number per furnace	1
Amount of air	35,000 Nm^3/h
Static pressure	460 mmAq
Temperature	30 C
Number of revolutions	1,670 rpm
Drive type	Belt drive
Motor size	150 HP
Flue gas fan (I.D. Fan)	
Number per furnace	1
Amount of gas	107,000 Nm^3/h
Static pressure	170 mmAq
Temperature	350 C
Number of revolutions	1,010 rpm
Drive type	Belt drive
Motor size	220 HP
Recirculation fan	
Number per furnace	1
Amount of air	45,000 Nm^3/h
Static pressure	220 mmAq
Temperature	350 C

Number of revolutions	1,460 rpm
Drive type	Belt drive
Motor size	150 HP
Cooling air fan for by-pass damper	None
Steam air heater	None

CHIMNEY

Chimney	
Type	Concrete with steel flue
Number	1 per 4 furnace
Diameter at top	2.8 m
Height	150 m
Gas velocity at top	max. 27 m/sec

AUXILIARY BURNING PLANT FOR FURNACE	Not necessary

DUST COLLECTING PLANT

Electrostatic precipitator	
Number per furnace	1
Capacity	107,000 Nm^3/h
Gas temperature	
Operating	300 C
Maximum	350 C
Dust content	
Inlet	7.5 g/Nm^3
Outlet	0.15 g/Nm^3
Efficiency	98%
Pressure drop	5-10 mm water
Multi-cyclone	None

CLINKER AND FLY ASH TRANSPORTATION PLANT

Clinker transportation equipment under clinker chute	
Type	Submerged conveyor stainless steel laminated
Number per furnace	1
Capacity	4 tonnes/h
Speed	3 m/min
Width	1.1 m
Length of traveling	13 m
Ash transportation equipment under grates and rotary kiln	
Type	Vibration conveyor
Number per furnace	1
Capacity	0.6 tonnes/h
Speed	.6 - 1.2 m/min
Width	diam. 300 mm
Length	14.5 m
Ash transportation equipment under boiler or gas cooler	
Type	Vibration conveyor (screw conveyor submerged stainless steel
Number per furnace	1
Capacity	0.6 tonnes/h
Speed	.6 - 1.2 m/min
Width	diam. 600 mm
Length	6.3 m
Fly ash transportation equipment under Dust collector	
Type	Fluidizing
Number per furnace	4
Capacity	0.6 tonnes/h

Specific weight of clinker	1.0 tonnes/m^3
Storing Capacity	4 days
Clinker transport	
Number	1 plus 1 stand-by
Type	Laminated steel conveyor
Length of traveling	50 m
Width	1 m
Speed	3 m/min.
Disposal of clinker and fly ash	Landfill
Boiler	
Method of gas cooling	Waste heat boiler
Boiler	
Type	Hot water boiler water tube
Number per furnace	1
Design pressure	16 kg/cm^2g
Working pressure	6 kg/cm^2g
Hot water temperature	120 C
Feed water temperature	75 C
Capacity	21.5 x 10^6 kcal/h
Heating surface	
Radiation heating surface	330 m^2
Convection heating surface	330 m^2
Superheater	None
Economizer (Normal steel tubes)	455 m^2
Economizer (Casted steel)	720 m^2
Gas air heater	None
Gas temperature	
Inlet	800 C
Outlet	280 - 320 C

Clinker transport	
Number	i plus 1 stand-by
Type	Laminated steel conveyor
Length of traveling	50 m
Width	1 m
Speed	3 m/min.
Disposal of clinker and fly ash	Landfill
Boiler	
Method of gas cooling	Waste heat boiler
Boiler	
Type	Hot water boiler water tube
Number per furnace	1
Design pressure	16 kg/cm^2g
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Convection heating surface	330 m^2
Superheater	None
Economizer (Normal steel tubes)	455 m^2
Economizer (Casted steel)	720 m^2
Gas air heater	None
Gas temperature	
Inlet	800 C
Outlet	280 - 320 C
Amount of gas	
Lowest calorific value	33,000 Nm^3/h
Average calorific value	77,000 Nm^3/h
Highest calorific value	98,500 Nm^3/h
Boiler outlet gas temperature control	Yes, automatic
Heat utilization	District heating
Water spray gas cooler	None

Boiler cleaning equipment	
Type	Shot cleaning
Soot blower	None
Hot water cooler	
Type	Air cooler
Number	2
Capacity	370 tonnes/h
Heat exchanged	18.3×10^6 kcal/h
Hot water temperature	
Inlet	115 C
Outlet	60 C
Hot water pressure	10 kg/cm^2g

OVERALL SYSTEM SCHEMATIC

Figure 14-1 shows the cross-sectional schematic of the Copenhagen: Amager plant designed and built by Volund A/S.

COMMUNITY DESCRIPTION

Geography

Figure 14-2 is a map of the Copenhagen metropolitan area. Copenhagen itself is located on the east coast of Denmark, not far from Sweden.

The Amager refuse-fired steam generator is shown at the north end of Amager Island just southeast of downtown Copenhagen. Its twin unit "Vest" or "West" described in Trip Report 15.

The terrain is rather flat, which is typical of eastern Denmark. The Amager plant (see Figure 14-3) is located right on the canal separating Amager Island from the main Danish island to Amager's north. Amager Island was originally unimproved swamp land that has been "poldered" with pilings, dykes, and debris fill over many centuries. Being at sea level did interfere with construction in two ways. First, numerous pilings had to be sunk. Secondly, the refuse bunker pit had to be shallow and encased in special water protective coatings.

The population in the City of Copenhagen proper has fallen from 550,000, 10 years ago, to 430,000 presently. Reasons are typical of those in many large cities. Basically young families are moving to the suburbs, leaving the city for students, government workers, retired people, and those wishing a short commute to work. The Amager plant serves about 620,000 people in central, east, and southern Copenhagen and those residents of the Amager Island.

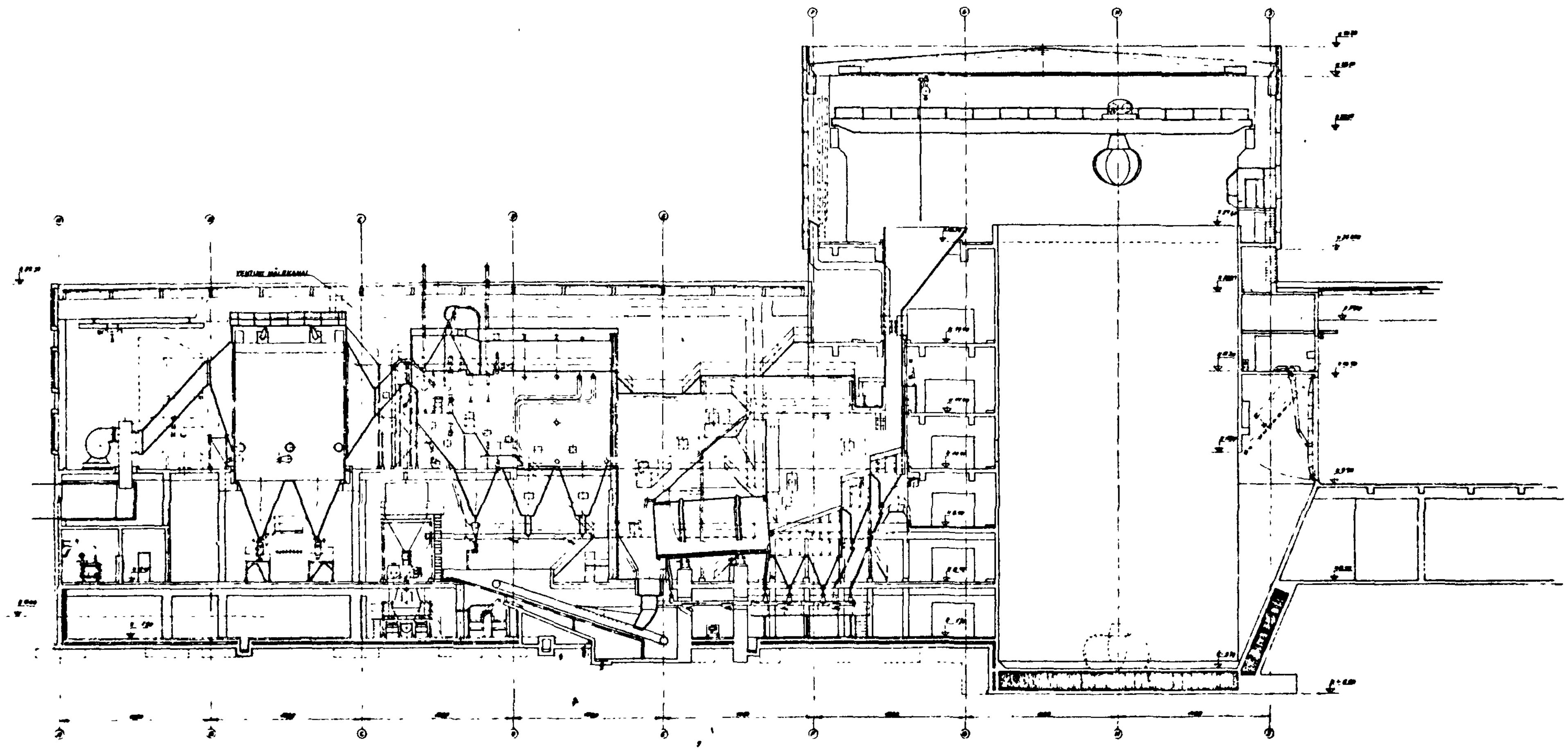


FIGURE 14-1. ENGINEERING DRAWING OF COPENHAGEN:AMAGER

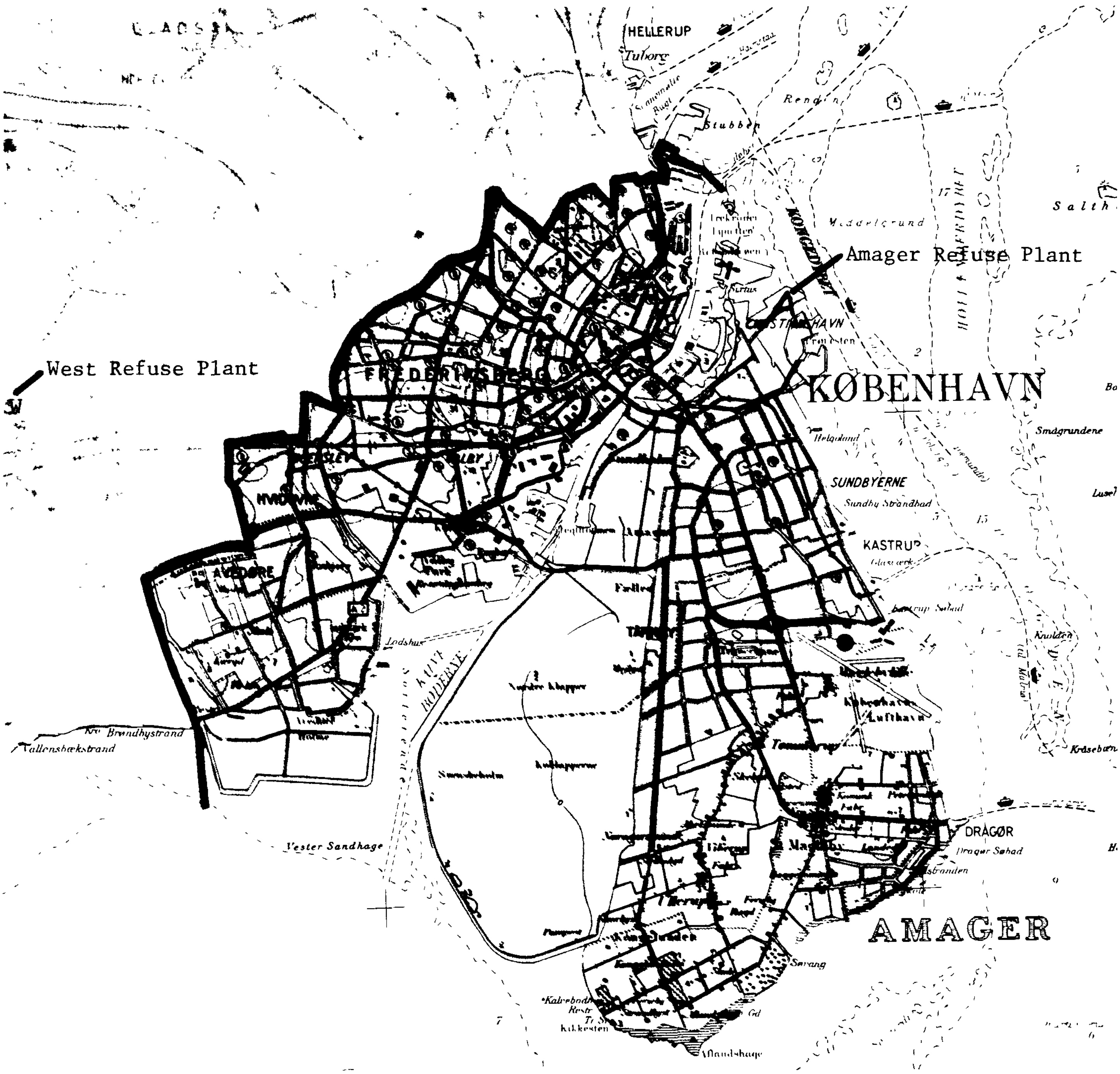


FIGURE 14-2. MAP OF COPENHAGEN, SOUTH AND EAST METROPOLITAN AREA SERVED BY THE AMAGER PLANT

FIGURE 14-3. COPENHAGEN:AMAGER PLANT LOCATED ON CANAL

SOLID WASTE PRACTICES

Solid Waste Generation

The "immediate" Copenhagen metropolitan area, as served by the two large Volund plants (Amager and West), has a total population of 1,137,978 and generates 509,246 tonnes (560,171 tons) per year as shown in Table 14-1.

Five communities sent 253,439 tonnes (278,783 tons) to Copenhagen: Amager during the 1975/1976 fiscal year. On a 7-day burning basis, about 694 tonnes (763 tons) per day were consumed. These figures compare with the rated capacity of 864 tonnes (950 tons).

Collections are higher than the national average from offices, stores, etc. However, household waste collections are lower than normal. Bulky and garden waste is collected separately and usually landfilled. Only 9 percent of Copenhagen's residents have gardens. Vegetative waste amounts to 10 percent of the total household waste as an annual average.

Household generation rate figures were provided as follows:

City of Copenhagen	0.8 to 1.0 kg/person/day
Suburbs	1.2 to 1.5 kg/person/day
Metropolitan Area	1.0 to 1.4 kg/person/day

In 1975-1976, households in the Amager district generated 351 kg per person. Adding commercial and industrial refuse brings the total to 466 kg per person. This translates to a combustible receivable rate of 1.226 Kg (2.7 pounds per day)/person day.

The refuse composition has been changing over the years to about these figures:

	1964/1965	1970	1977
Heat Value (kcal/kg)	1,600	1,800-2,000	2,200
Moisture (percent)	35	33	28
Combustibles (percent)	40	45	49
Noncombustibles (percent)	25	22	23

TABLE 14-1. POPULATION AND REFUSE CONSUMPTION IN THE IMMEDIATE COPENHAGEN METROPOLITAN AREA

Population (Inhabitants)	April 1, 1974	April 1, 1975	April 1, 1976
I/S Amager Area	524,955	580,556	568,343
I/S Vest* Area	581,333	575,996	569,635
TOTAL	1,106,288	1,156,552	1,137,978

Refuse Consumption (Tonnes)	1974-1975	1975-1976	1976-1977
I/S Amager Plant	224,449	255,488	255,807
I/S Vest Plant	215,224	234,230	253,439
TOTAL	439,673	489,718	509,246

* Vest is translated to West.

Solid Waste Collection

Delivery is by local garbage trucks. Therefore, there is little, if any, bulky waste burned.

The overall cost for collection and disposal averages about 465 D.Kr. ($95) per year per person throughout Denmark.

Waste has been collected since 1898 by a not-for-profit society, Renholdnings Selskabet. Much could be written regarding this very successfful organization. One item of interest is that each walking collector has a computer printout that tells him exactly how many Danish Kroner he will earn by "traveling 17 horizontal steps, three vertical steps, picking up a 10 liter can ...".

Comment: We are unaware of any collection system as detailed and filled with motivational factors as the system at Renholdnings. Further information is available.

Solid Waste Transfer

The transfer activity at Amager is unlike that of West. A large transfer station is shown under construction in 1974 in Figure 14-4. The area's industrial waste and household bulky waste is taken to this transfer station located on the grounds of the Amager plant. Some of the waste is then transferred to the Uggelose landfill located 37 km (23 mi) northwest of Amager and inland. During 1975-1976, 32,374 garbage trucks entered the transfer station. Some combustible waste was taken to the refuse burning plant. About 13,723 transfer trailer loads were taken to the Uggelose landfill.

Hazardous waste collected at the Amager plant is later transported to the Federal hazardous waste treatment center at Nyborg, Denmark.

FIGURE 14-4. TRANSFER STATION UNDER CONSTRUCTION AT AMAGER. PHOTO TAKEN FROM WINDOW AT THE AMAGER REFUSE BURNING PLANT. THE STORAGE YARD OF THE RENHOLDNINGS SELSKABET COLLECTION ORGANIZATION IS SHOWN IN BETWEEN.

Provisions to Handle Bulky and Noncombustible Wastes

Homeowners must call the city of residence if they wish their bulky waste picked up.

The self-contained Amager plant itself has no provision to handle bulky wastes. As previously stated, adjoining the plant is the transfer station. Trucks with bulky or noncombustible loads are weighed at the same scale as is household refuse. Referring back to the aireal photo in Figure 14-3, the trucks behind of the chimney, up and around to the left out of the picture, and to the transfer station.

Figure 14-5a shows the ramp leading to the completed station. An operator is about to dump a load of bulky material into a Von Roll scissor shear in Figure 14-5b. Size reduced combustible material is then hauled directly to the refuse burning plant. If most of the material is noncombustible, it is compacted, weighed (see Figure 14-5c), and sent to the Ugglose landfill (30 km (19 mi) northwest of Amager.

The Von Roll shear can process up to 80 m^3/hour (105 yd^3/hour). It operates intermittently and has a hydraulic drive. One man operates the crane and shear on the day shift. The maintenance record has been very good.

Solid Waste Disposal

The greater* Copenhagen metropolitan area is now served by eight refuse-fired energy plants. All of the following are within a 32 km (20 mi) semicircle radius of Copenhagen:

- Vest (West)
- Amager
- Brondby
- Taastrup
- Roskilde
- Albertslund
- Horsholm
- Helsinor

*"Greater" metropolitan area with 8 plants is differentiated from the "Immediate" Copenhagen metropolitan area having only the Amager and West plants.

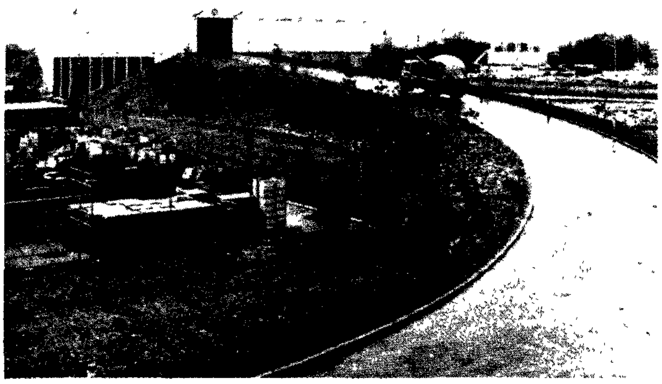


FIGURE 14-5a. RAMP LEADING TO TRANSFER STATION

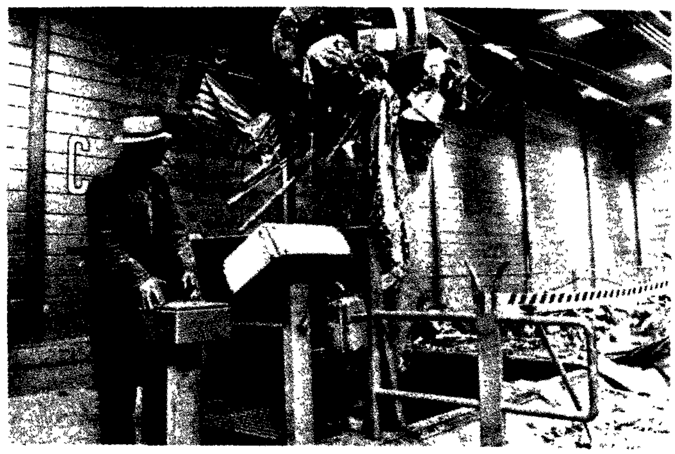


FIGURE 14-5b. BULKY WASTE BEING DROPPED INTO THE VON ROLL SCISSOR SHEAR

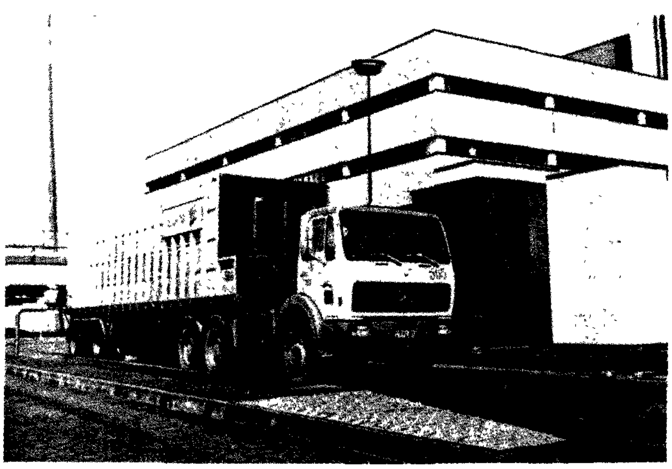


FIGURE 14-5c. TRAILER LOAD FROM THE TRANSFER STATION BEING WEIGHED BEFORE TRANSPORT TO THE UGGELOSE LANDFILL

Figures 14-6a and 14-6b show landfill operations at the Uggelose site northwest of Copenhagen.

In previous years, composting was practiced at two sites west of Copenhagen. Eventually, there was some talk about mercury and cadmium content. Perhaps too, the market for compost material was not great. For whatever reasons, it was closed. Now, however, as is often the case, composting is returning at a new site northwest of Copenhagen beginning in January, 1978.

FIGURE 14-6a. LANDFILL OPERATIONS AT UGGELOSE, DENMARK

FIGURE 14-6b. LANDFILL OPERATIONS AT UGGELOSE, DENMARK

DEVELOPMENT OF THE SYSTEM

Waste-to-energy began in Copenhagen in the early 1930's with the 1932 commissioning of the two 144-tonne (158 ton) per day Volund grate/rotary kiln furnaces at Gentofte, each with a three-drum boiler as shown in Figure 14-7. The steam was used to make electricity as specified by the city's Electrical Board. This construction was followed by two similar Volund units at Frederiksberg in 1934.

These two plants served Copenhagen well for 40 years. During that time, these plants had reached their capacity. Therefore excess refuse had to be landfilled both inland and on the sea coast. Referring back to the map, Figure 14-2, notice the large undeveloped area in the western part of Amager Island. This was basically low swamp land that has been filled in with both demolition debris and household refuse.

During the 1960's, when knowledge of landfill leachate damages became better known and when neighbors became upset over blowing trash, etc., local citizens groups on Amager Island were effective in getting the attention of elected officials.

For a time, it seemed that each community wanted to independently solve its solid waste disposal problems. Finally, one of the island communities decided to build a resource recovery plant. Others soon followed. Eventually the City of Copenhagen joined in the development.

Incidentally, the excitement about Amager encouraged the residents west of Copenhagen to develop a similar system now called "Vest" or"West". Eventually, the Copenhagen Gas and Electric Company conducted a study that resulted in the recommendation that two new refuse-fired hot water generators be built to replace Gentofte and Frederiksberg.

Of note was that the competitive approach provided both organizations with a quantity discount if both purchased similar units.

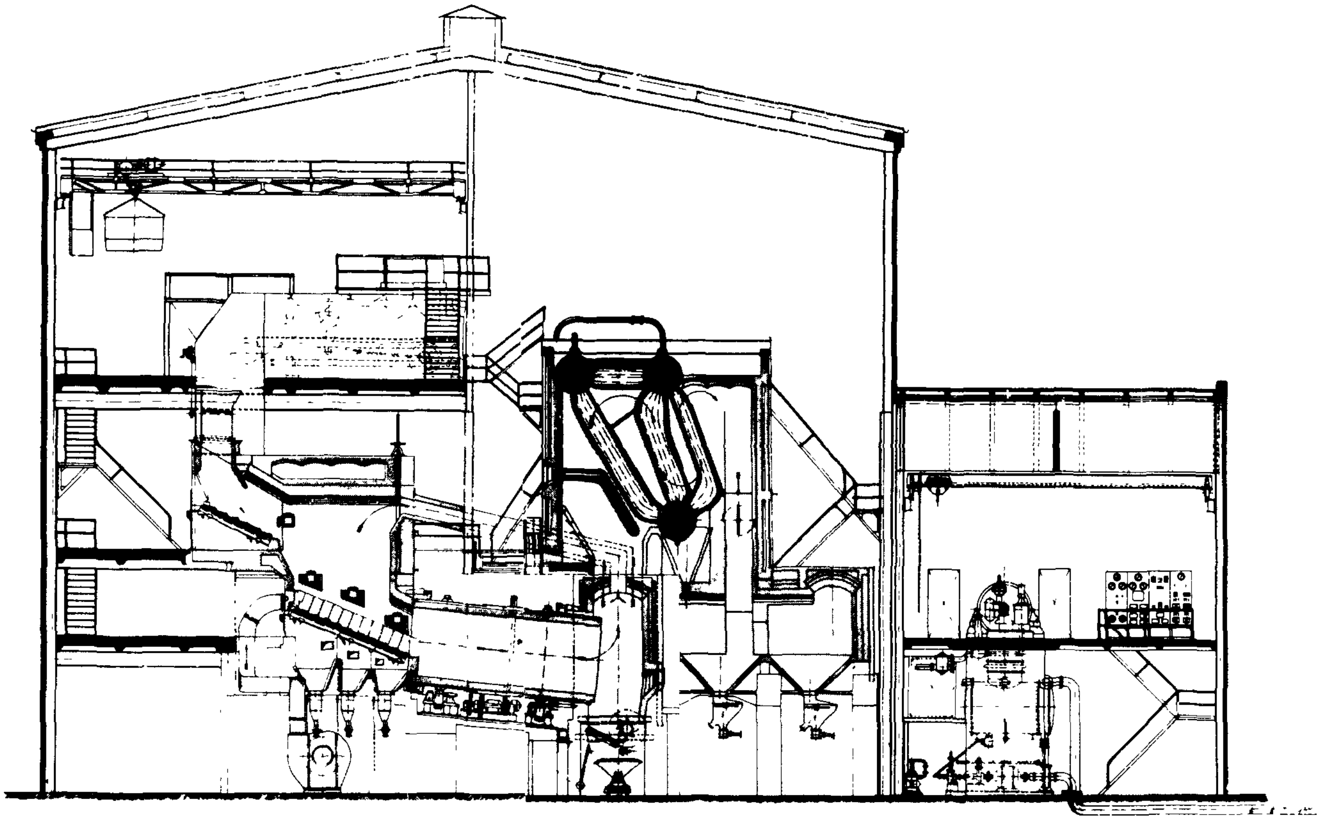


FIGURE 14-7. FIRST VOLUND SYSTEM BUILT AT GENTOFTE IN 1932 AND DECOMISSIONED 40 YEARS LATER IN 1972

The competitors at Amager were:

- Heenan-Froud
- Martin
- VKW
- Volund
- Von Roll

Officials remember that VKW, Volund, and Von Roll had the lowest single unit prices (i.e., nonquantity discount). Other excellent Volund plants in Denmark, the long history (40 years) of successful operations at Gentofte and Frederiksberg, the low (maybe not the lowest) single plant price, the quantity discount, and the Volund headquarters being nearby all contributed to the decision favoring Volund.

Construction began in 1965 with 2 year's of sea and earth reclamation. Plant construction began in 1967 and was completed in 1970. Construction at Amager preceded work at West. Both began operation within 2 months of each other.

Improvements were made to both plants above what was technically specified in the contract. Unfortunately the Amager building was not fit to accept the improved ash transport system as was done at West. The refuse input cranes and the ash discharge equipment are just two examples that are discussed later in this report.

Copenhagen:Amager is owned by the five communities it serves, as are listed in the "Organization" section at the end of this trip report. Amager started operations in February 28, 1974 with three furnaces, each designed to burn 12 tonne (13.2 ton) per hour assuming 2,500 kcal/kg.

> Comment: Many of the more precise interviewees refer to "xx tonnes per hour assuming y,yyy kcal/kg". After all, the limiting factor is <u>not</u> how much refuse weight can mechanically be pushed through the unit. Rather, the limiting factor is the heat release rate that will not unduly affect system reliability. Figure 14-8 shows the development of a Volund system.

Volund's Relation to the North American Market

Volund A/G initiated activity in North America Janauary 9, 1948 with the F. L. Smidth & Co. Smidth had the "sole and exclusive rights to make, sell and/or use the VOLUND INCINERATOR SYSTEM ...in the United States...Canada and Mexico".

Also in 1948, Smidth and The Hardaway Construction Company of Columbus, Georgia formed a joint venture company called International Incinerators Incorporated (III) with offices in Atlanta, Georgia. III was to "devote its best efforts to an aggressive attempt to obtain orders from purchasers ... (in North America)... for the sale or installation of apparatus and equipment made in accordance with the VOLUND INCINERATOR SYSTEM".

With this charter, III sold 13 municipal waste incinerators, 2 of which had energy recovery. They also sold 3 industrial waste incinerators. During this time of cooperation, III utilized many of the Volund A/G patents and site-specific drawings. In addition, III developed many of their own techniques and filed patents. Eventually many of the early Volund A/G patents expired. Yet Volund A/G continued to file patents in America.

With the Congress passing the Clean Air Act of 1970 and the ensuing regulations on incinerators, many units closed. Few new orders (regardless of manufacturer) were placed after 1970. In fact III had some of the very last orders. Nevertheless the future looked bleak. III survived on their replacement parts business.

Eventually the license agreement between F. L. Smidth (the 50 percent owner of III) ceased effective December 31, 1975. Smidth then sold its shares to the other original joint partner The Hardaway Construction Company.

Subsequently Volund A/G and III (now 100 percent owned by Hardaway) were not able to come to agreement on a new license.

Volund A/G continued efforts to find a new licensee. Finally a joint venture corporation was founded and is known as Volund USA (VUSA).

An abreviated name used orally is VUSA. It is owned jointly by the following parties:

Volund A/G (Glostrup, Denmark)	30 percent
Waste Management, Inc. (Oak Brook, Illinois)	30 percent
Jack Lyon & Assoc. (Washington, D.C.)	30 percent
Others	10 percent

We have been informed that VUSA would like potential purchases of VOLUND INCINERATOR SYSTEMS to contact:

Sales, Construction, Operations

Mr. Ronald Heverin
Director of Marketing
Advanced Systems Group
Waste Management, Inc.
900 Jorie Boulevard
Oak Brook, Illinois 60521

Engineering, Design, Start-up

Mr. Gunnar Kjaer
President
Volund USA
900 Jorie Boulevard
Oak Brook, Illinois 60521

Frankly, both Volund A/G and III lay claim and probably desire recognition for these 13 or so American plants. All plants are shown in the current inventory published separately by Volund A/G and III.

Effectively, this means that a community desiring "something that looks like a Volund grate followed by a rotary kiln" has two potential vendors. Some would speculate that this is an unnatural situation that still has not settled.

Volund has prepared a block flow diagram showing how they view the developmental process for these systems (see Figure 14-8).

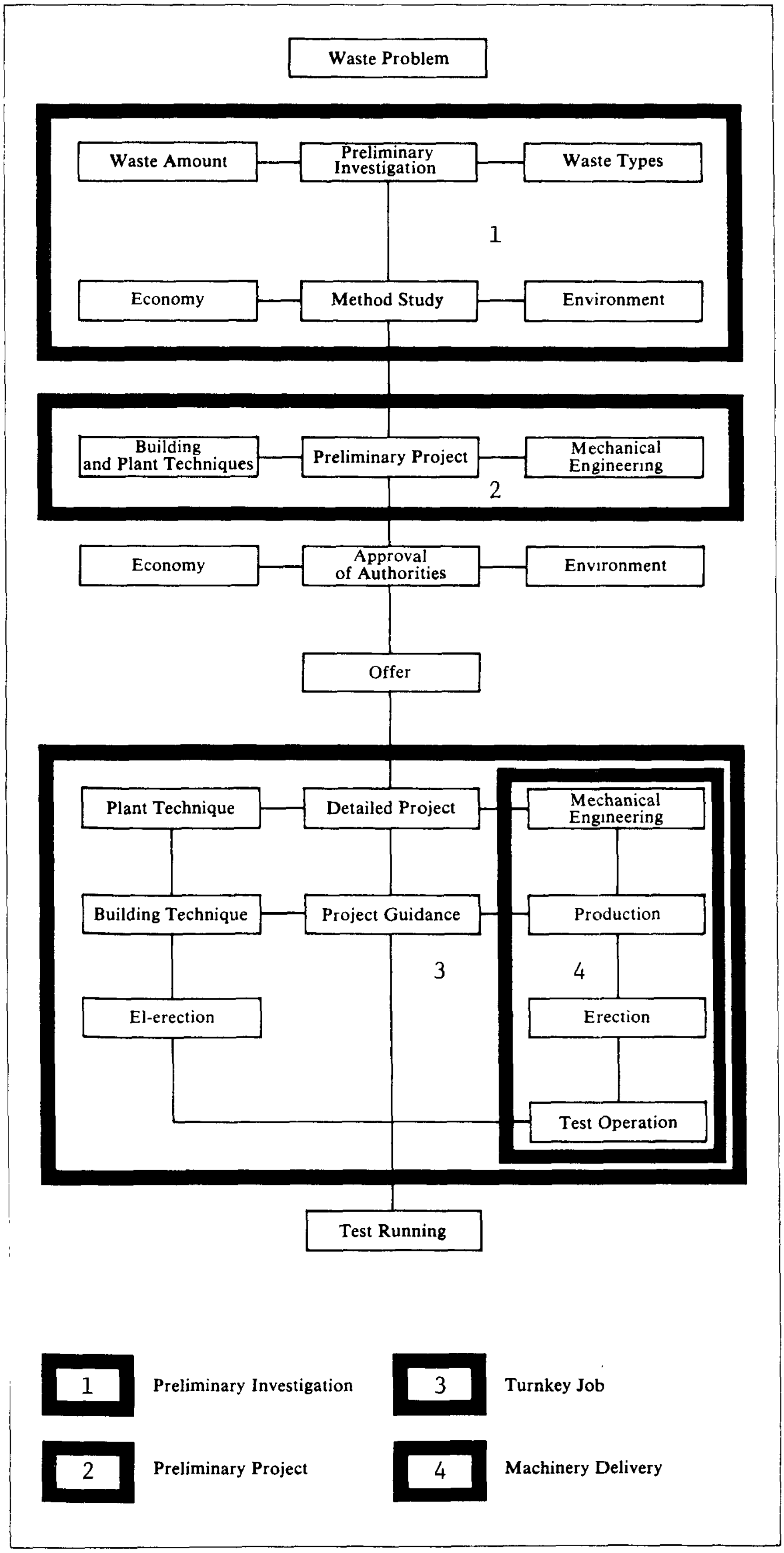


FIGURE 14-8. VOLUND'S PROCEDURE FOR SYSTEM DEVELOPMENT

PLANT ARCHITECTURE AND AESTHETIC ACCEPTABILITY

Plant architecture at both the Amager and West plants is excellent to outstanding. Yet there are important differences between the two plants caused (1) by the site location, and (2) partly by the type of construction contract.

The Amager site is located on "new" land that is an extension of Amager Island (see Figure 14-9). Being right on the sea, the refuse pit is shallow and limited to only 4 m (13 ft) below sea level.

The Amager plant is situated on a land parcel of 31,500 m^2 (7 acres) leased from the City of Copenhagen. The building itself is on 8,400 m^2 (1.87 acres). The floor space within the plant totals 25,374 m^2 (5.64 acres). Finally, the cubic content of the building is 244,805 m^3 (8.6 million ft^3).

It is truly in a "nonresidential" industrial area and was thus designed with a functional rectangular industrial theme. West, by contrast, is in a residential neighborhood and has interesting modular building block and exterior wall themes. The landscaping effect (and cost) was much more at West.

Of note is that since 1970, the Copenhagen Town Hall has not received a single complaint from the citizens about Amager waste disposal.

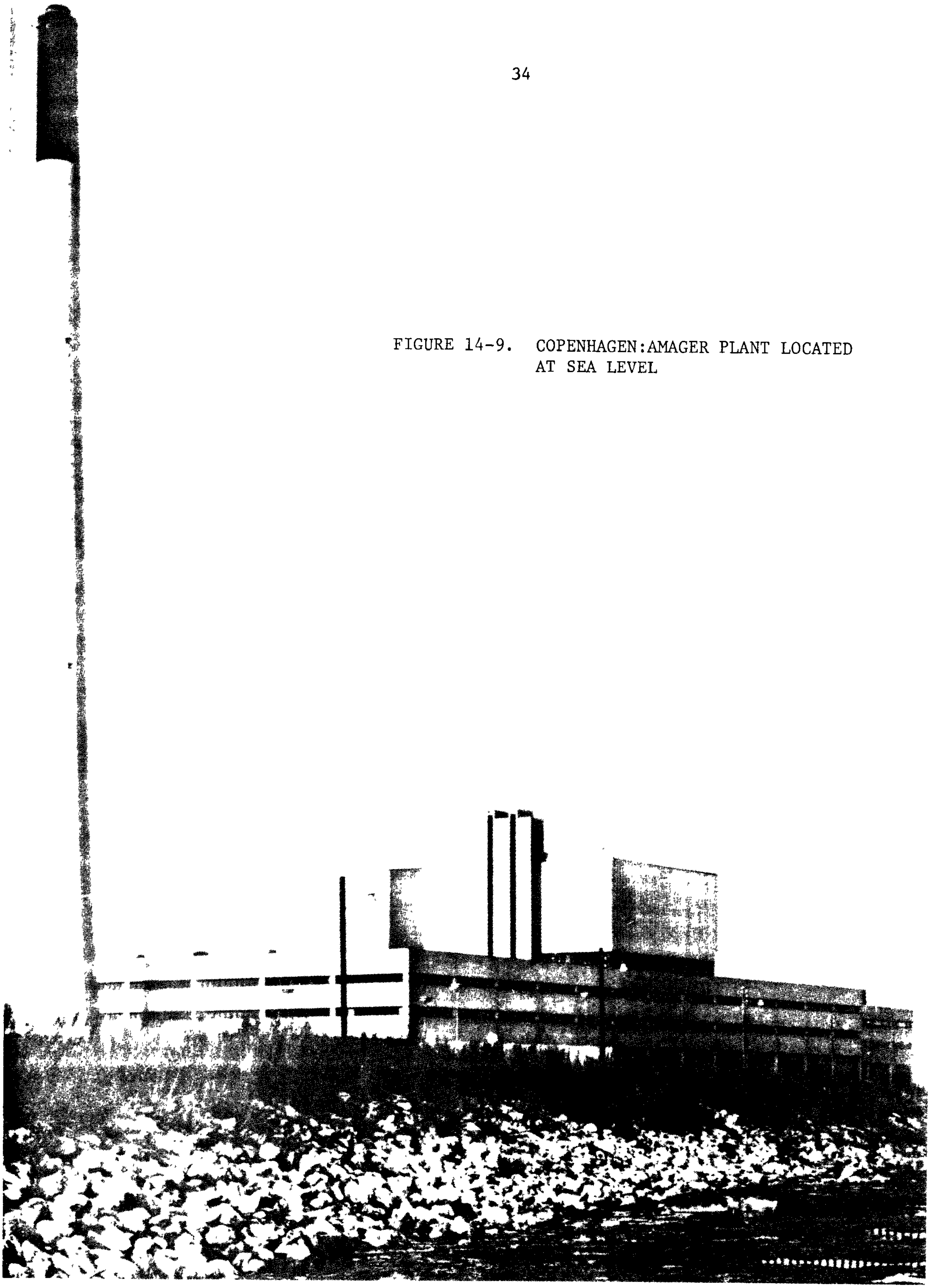
Perhaps another reason for Amager's modest but attractive appearance is that vendor competition for construction of Amager was under a traditional "fixed price" contract where most items were agreed to ahead of time. West, however, was built under a "cost plus fixed fee" arrangement. Thus, at West, there was an increased tendency to opt for the "best" but not necessarily for the "most economical".

Despite the identical refuse input requirements and similar processing equipment, there was more attention to aesthetics at the West plant. As such, West was 25,000,000 D.Kr. ($4,800,000) more expensive.

The building height is 25 m (83 ft). The stack is very tall at 150 m (492 ft).

At both plants, everything that could produce noise is enclosed. The tipping floor for refuse collection trucks is fully enclosed. The electrostatic precipitator, often on plant roofs, is enclosed.

FIGURE 14-9. COPENHAGEN:AMAGER PLANT LOCATED AT SEA LEVEL



The administration portion of the building is indistinguishable as part of the total monolithic structure. The only clue to its position is the semicircle parking lot clearly seen in the previous Figure 14-3.

Figures 14-10a, b, c, and d show four very clean rooms where Amager staff work. The rooms are attractive, well lighted, functional, and generally pleasant. Comments were made several times during Battelle's visits in Scandanavia that such pleasant surroundings are necessary to attract and keep the desired kind of employees.

A publication, Amager-forbraending Interersentskab[1], has several paragraphs of interest regarding architecture.

> "The building is constructed of reinforced concrete, with an exterior cladding of concrete components. The entire north wall has been designed so that it can be moved if the plant is extended and has, therefore, been built as a light steel construction with aluminum cladding. The top of the silo is likewise covered with aluminum. The size of the lot permits an extension with an additional three furnaces to a total of six furnaces, and the technical assistance rooms, pump rooms, etc., as well as administration offices and personnel rooms have been given the proper dimensions for this purpose."

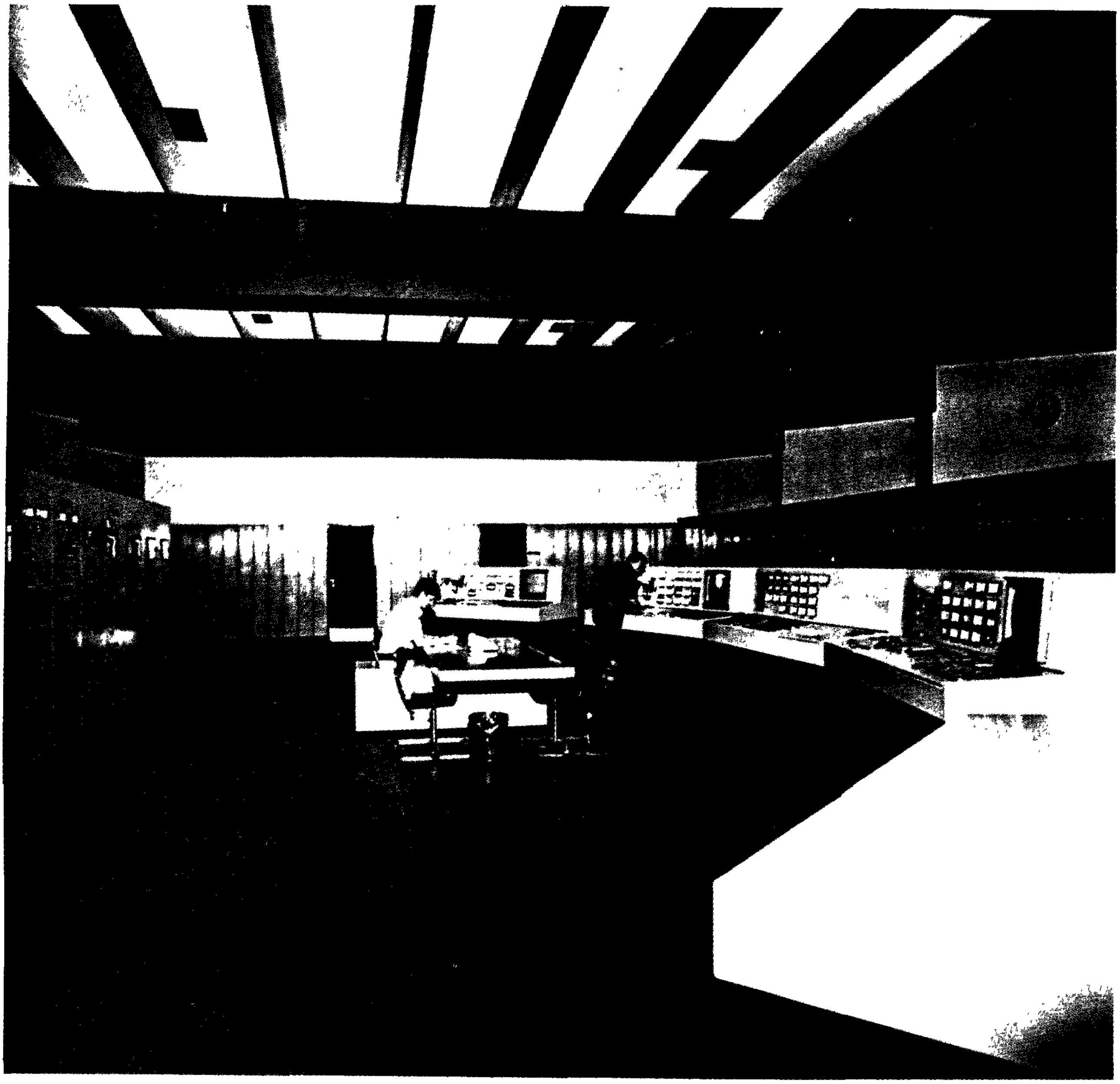


FIGURE 14-10a. CONTROL ROOM AT COPENHAGEN:AMAGER

FIGURE 14-10b. LOBBY ENTRANCE

FIGURE 14-10c. CAFETERIA

FIGURE 14-10d. CONFERENCE ROOM

TOTAL OPERATING SYSTEM

Maximum Rated Capacity

Battelle's host for the Volund visit was Gabriel Silva Pinto. In April, 1976, he wrote an excellent article in an internal Volund publication* that discusses basic design of the total operating system. The following summarizes the article and Figure 14-11.

For purposes of the vendor's guarantee to the customer, there must be a clear understanding of the relation between Maximum Rated Capacity (MRC) and Lower Heating Value (LHV). The numbers used in the example figure are those associated with the Volund Rotary Kiln Furnaces.

For each furnace designed by Volund, a theoretical diagram, similar to Figure 14-11, is developed. Its purpose is to show how the MRC (tonnes/hr) is a function of the refuse's LHV (kcal/kg).

As an example, assume that the LHV is 2,000 kcal/kg.** Typically, such municipal solid waste has the following composition:

	Percent
Inerts	25.0
Moisture	30.0
Combustibles	
Carbon	8.6
Cellulose	34.8
Plastics	1.6
Total Combustibles	45.5
TOTAL	100.0

* See Reference 4.

** Amager was designed with expected average LHV of 2,000 kcal/kg. However, the actual is closer to 1,800 kcal/kg.

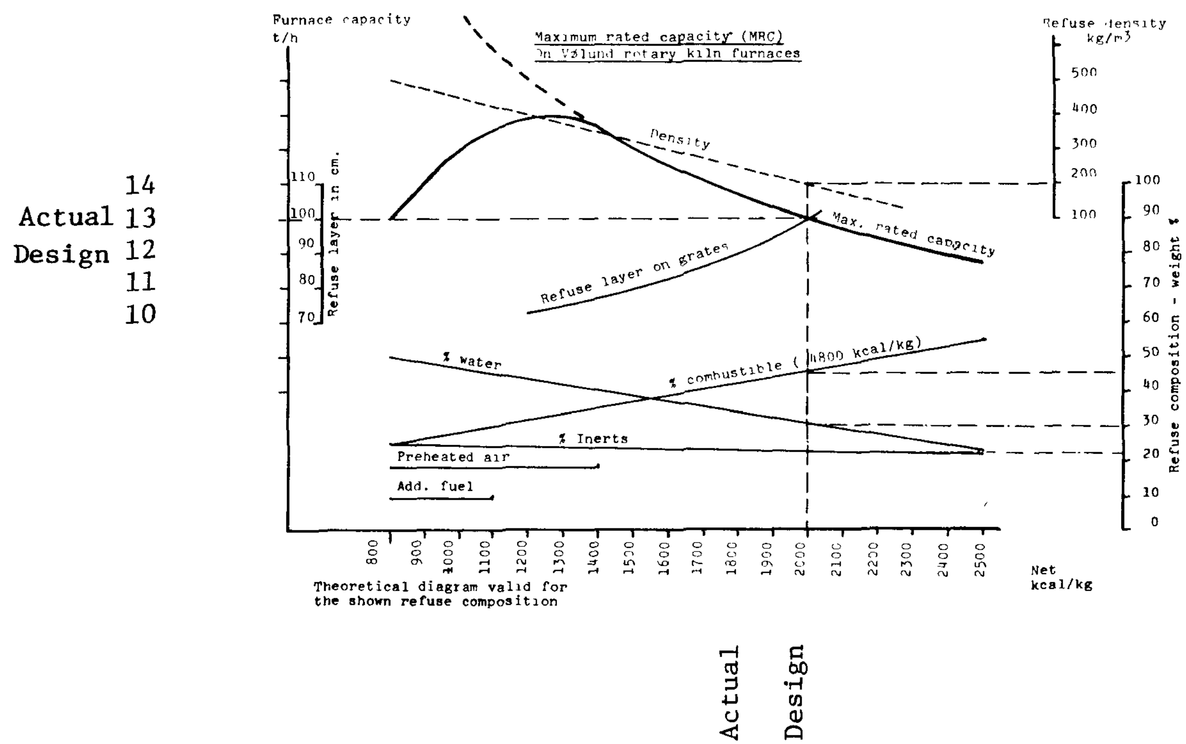


FIGURE 14-11. MAXIMUM RATED CAPACITY ON VOLUND ROTARY KILN FURNACES

The refuse feeder is to be adjusted so that the refuse layer on the grate is 1 m (3.3 ft). This type of refuse has an average density of 200 kg/m^3 (336 $pounds/yd^3$).

More must be known about the specific system before the MRC answer (in tonnes/hr) can be given. The effective grate area must be known. The following formula relates key variables:

$$MRC\left(\frac{tonnes}{hour}\right) = \frac{\text{Effective Grate Area }(m^2)\ .\ \text{Grate Load}\left(\frac{kcal}{m^2.hour}\right)}{\text{Lower Heating Value}\left(\frac{kcal}{kg}\right)\ .\ 1000\left(\frac{kg}{tonne}\right)}$$

At this point, some rules of thumb need to be applied:

- For hotter refuse with LHV of 1,800 to 2,500 kcal/kg, the grate load ranges from 600,000 to 650,000 $kcal/m^2$. hr.
- For cooler refuse with LHV under 1,800 kcal/kg, the grate load ranges from 450,000 to 550,000 $kcal/m^2$. hr.

Experience of Volund must be used to actually estimate the grate load. But once estimated, the capacity can be determined. Mr. Pinto's example does not refer to any one system. Therefore, we have arbitrarily added capacity figures of 10 to 14 tonnes per hour.

An important design consideration can be seen from the capacity versus LHV curve. It is uni-modal peaking at 1,200-1,400 kcal/kg. As an example, it is assumed that the plant is nominally designed to burn 12 tonnes per hour of refuse assuming it to have a 2,000 LHV.

Perhaps on a spring day, rain is excessive. The moisture percent rises from its normal 30 percent to 37 percent; the combustibles fall from 45 percent to 38 percent; the density increases from 200 kg/m^3 to 300 kg/m^3; and the inerts remain constant. The air preheater remains unchanged and the use of any other fuel remains unchanged.

With the conditions of the wet waste given, the operator may increase the feed rate, raise the feed layer thickness to 120 cm (3.9 ft), and thus increase the throughput from its nominal 12 tonnes/hour up to 13 tonnes/hour.

This, of course, has a logical limit. If the refuse becomes too wet, full of inerts, and lacking in LHV, then less tonnes per hour can be processed. The furnace could easily choke on even 8 tonnes/hour of soggy rags and house furnace ashes if autothermic reactions are not possible.

In the other direction, above a LHV of 2,000, this particular furnace should process slightly less refuse per hour.

Mr. E. Blach, Volund's former chief engineer, wrote in 1969 an excellent paper outlining Volund's product offerings and its philosophy. The following section presents some of the philosophy of how plants should be operated. Several of his other sections appear later.

Forms of Operation

"The best way of running an incinerator plant is running it 24 hours a day, i.e., continuous operation. The big variations of temperature wear in a furnace and the auxiliary machinery than a steady operation, and corrosion and cleaning problems, etc. in the boiler part also decrease by continual operation. With regard to possibilities of maintenance and repair, continual operation is not possible for a one-furnace plant, and that is one of the reasons why an incinerator plant should usually consist of at least two-furnace units. Unfortunately, this is often not economically possible at the small plants.

An ideal way of operation for plants with several furnaces is obtained by always keeping a spare oven, while the other or the others run continuously. Through a convenient rotation so that the furnaces alternately are taken out of operation, there is plenty of time for inspection, maintenance, and repair of each furnace. Small damages can thus be found and repaired before they spread and require big and expensive repairs. At one-furnace plants, the possibilities of inspection are smaller and it can be tempting to let a long time pass between maintenance and repair stops so that the damages grow big and expensive to repair.

With noncontinuous operation, which in practice is a one- or two- shift operation, the furnace is stopped. When the operation is to be discontinued for 6 to 8 hours the furnace is fed with suitable amount of refuse proportionally to the standstill period. When the furnace is approximately full with refuse the grate movement and combustion air as well as I.D. fan are stopped. The natural draught will then keep a slow combustion, which develop sufficient heat to keep the plant warm all through so that it can quickly get up to full capacity, when it is started again. After a couple of hours, the temperature of the flue gases will be so low, that there is the risk of condensation, and thus corrosion in the convection part of the boiler. However, the boiler water still can be kept at full temperature, and the boiler chute can ensure minimum 70 C return flow temperature.

However, at stops of more than 6 to 8 hours, there must be taken special measures, such as by-pass with damper around the boiler and its convection part. This is a rather difficult construction to carry out in sufficiently strong and practical form because of the high temperatures.

Furthermore, it results in the operational inconveniencce that changing over cannot take place till the flue gas temperature is below 400 C, which normally means after 3 to 4 hours' stop. During weekend stoppages, the temperature of the boiler water cannot be maintained, and it will in this case be necessary also to keep the boiler warm by circulation of hot water."---perhaps by a standby boiler.

Operating Hours

The monthly operating hours for the three-line total are shown in Figure 14-12. At the recent average of 1,700 hours per month, the plant lines operated about 80 percent of the time.

During the 1975-1976 fiscal year (April 1 to March 31, the three furnaces together operated 19,663 hours or 75 percent of time available. This equates to an average of 13 tonnes (14.3 tons) per hour per furnace. This compares with a design capacity of 12 tonnes (13.2 tons) per hour per furnace. This higher refuse flow rate is consistent with the previous discussion on maximum rated capacity. Because the average calorific value is 1,800 kcal/kg, more refuse can be processed.

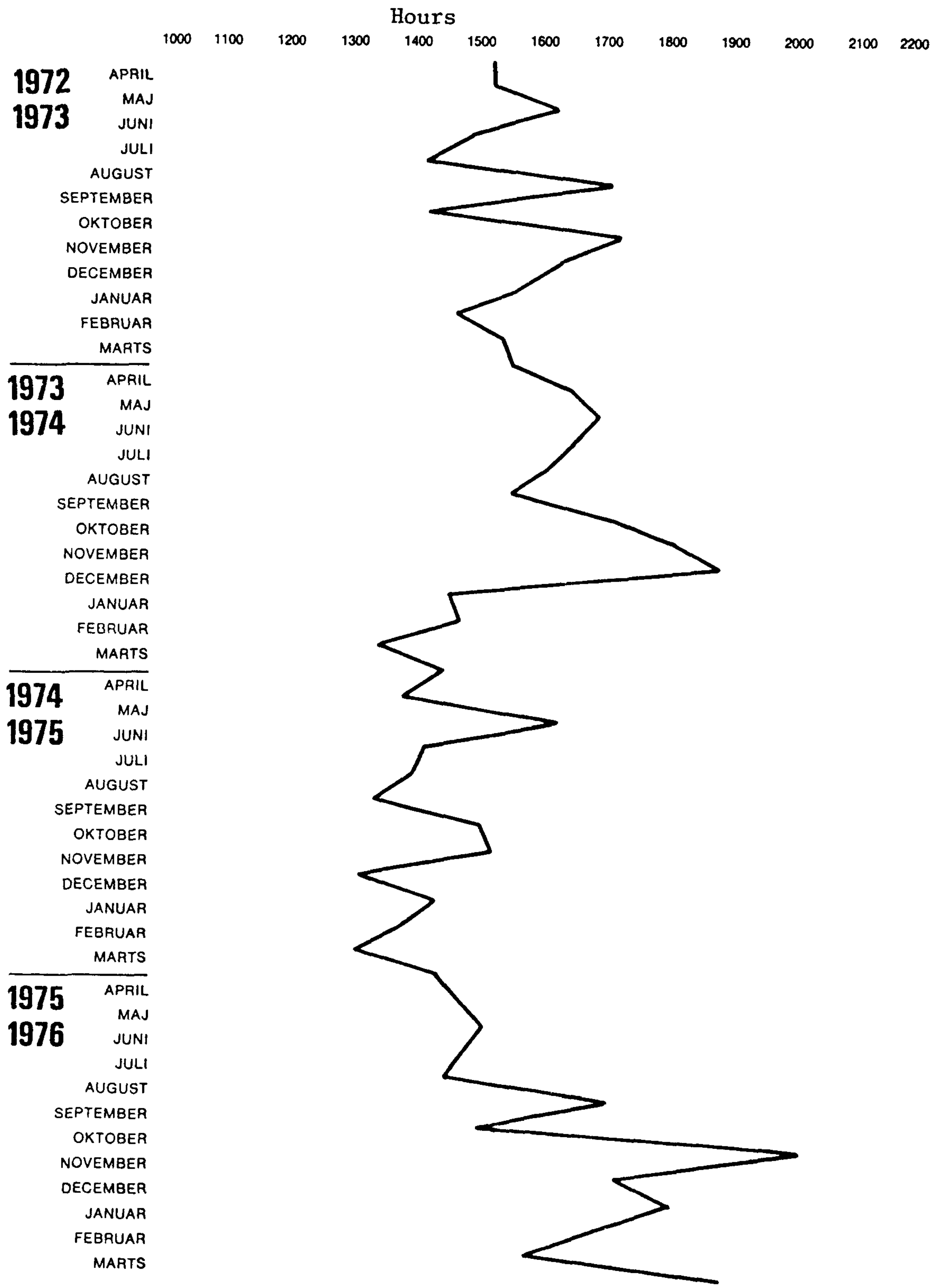


FIGURE 14-12. TOTAL (THREE LINES) OPERATION HOURS PER MONTH

Problems

Plant officials and Volund representatives have identified three old and partially solved problems as well as five continuing concerns. These are listed here and discussed later in the report.

Old Problems

- The crane was under capacity
- The grate-furnace refractory grossly failed due to poor anchoring
- The ash handling conveyor system had excessive wear due to fines buildup

Continuing Concerns

- The rotary kiln lining must occasionally be repaired
- The convection section has dew point corrosion due to the low temperature boiler feedwater
- The economizer must be manually cleaned every 1,500 to 2,000 hours, thus, setting the maintenance schedule
- The electrostatic precipitator corrodes slightly due to running "hot" when the economizer is clogged and is not properly cooling the flue gases
- The ash handling system, while improved, is still causing problems due to "fines".

REFUSE-FIRED HOT WATER GENERATOR EQUIPMENT

Waste Input

The plant receives normal household, commercial, hospital, and light industrial refuse (see Figure 14-13). Because of the chute size, the maximum refuse object size is 1 m (3 ft). Amager, in contrast to West, has no shredder. Instead, a transfer station adjoins the Amager plant.

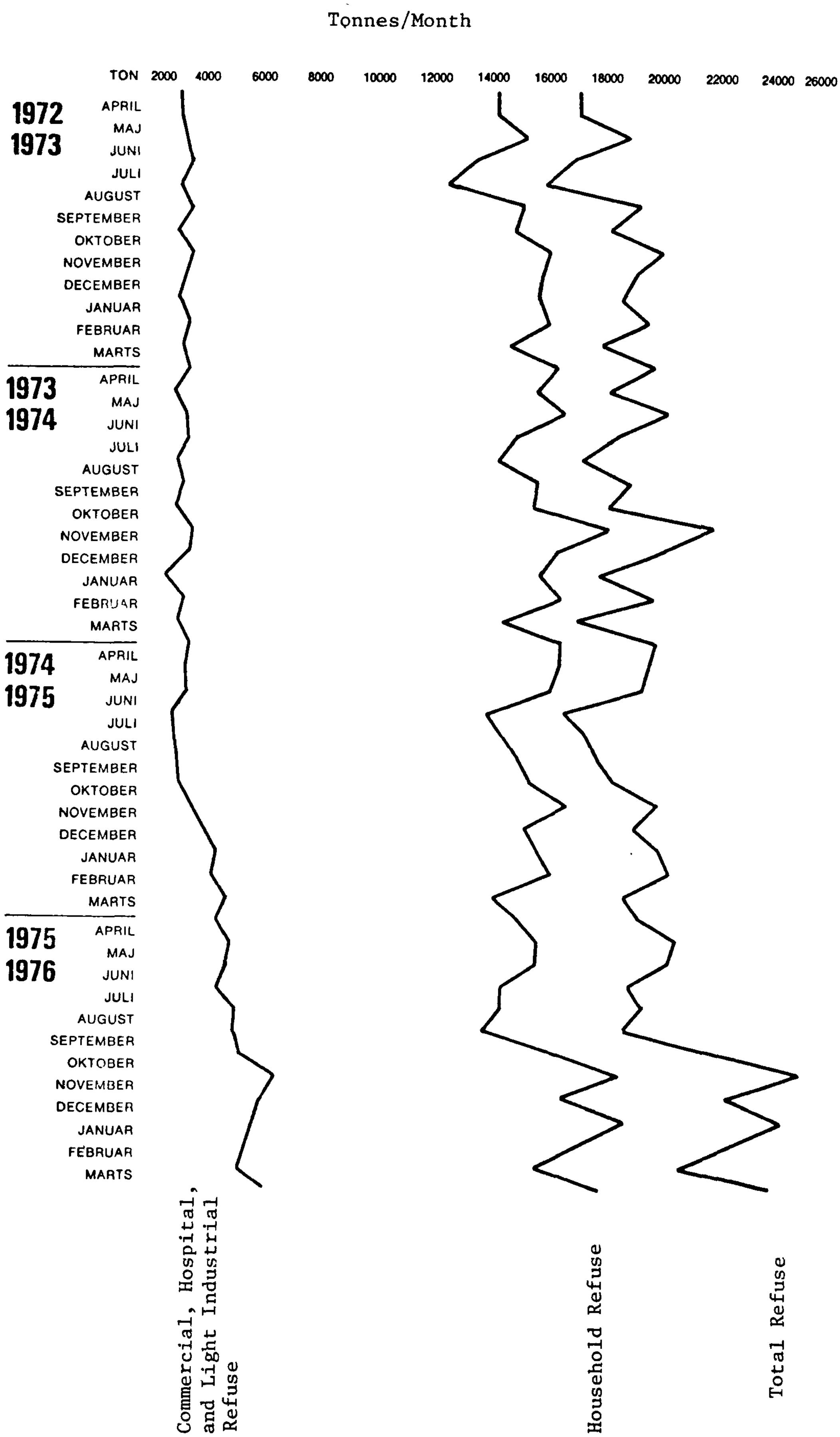


FIGURE 14-13. MONTHLY TONNAGE OF TOTAL, HOUSEHOLD, COMMERCIAL, HOSPITAL LIGHT INDUSTRIAL REFUSE WEIGHED AT THE COPENHAGEN:AMAGER SCALES

Because of the extensive vegetable farming on Amager Island, the plant receives much garden waste in the spring and summer.

The sewage sludge could be dischharged directly into the pit or in a special built silo with the necessary transport arrangement all of it in air tight execution. The waste oil would be stored in tanks and pumped to special burners.

At the moment the only sludge type burned in West and Auger are ridlings form the course grid at the water treatment plants. This matter which comes in containers is infiltrated and if it had to be treated in other way shedding would be necessary. On the Volund rotary kiln plant direct feeding is possible. While these containers come every day to the plants the amounts can not be measured in percentages of the total waste.

The plants at West and Amager were designed to burn waste oil, but a parallel development on the complete treatment of all hazardous chemical- and industrial wastes gave the best solution for the problem as the waste oil today is purified and resold at Nyborg. Thus the installations have never used the waste oil burning facilities.

The plant was designed for lower heating value waste between 1,000 and 2,500 kcal/kg (1,800 and 4,500 Btu/pound). The average is actually 1,800 kcal/kg (3,240 Btu/pound) which is lower than at West.

About 400 vehicles per day deliver waste to the pit. Ownership of the vehicles falls into three categories: private, public, and not-for-profit utility collection. In this third category, Renholdnings Selskabet (Cleaning Holding Company) was established back in 1898. This is the most noteworthy collection operation observed throughout the European visit. The company was formed in response to the series of epidemics or plagues in the latter part of the 19th century.

Weighing Operation

Arriving trucks proceed to one of the two load cells, 50 tonne (55 ton) scales manufactured by Philips of Holland (see Figure 14-14a). Drivers produce their universal plastic cards (Figure 14-14b) that identify the vehicle owner, etc. This information, along with the gross weight, is fed into the computer, where the tare weight, mailing address, etc. are stored.

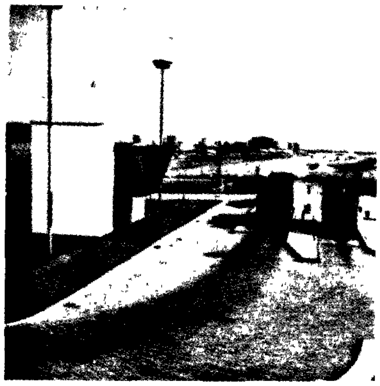


FIGURE 14-14a. SCALE HOUSE AND TWO SCALES

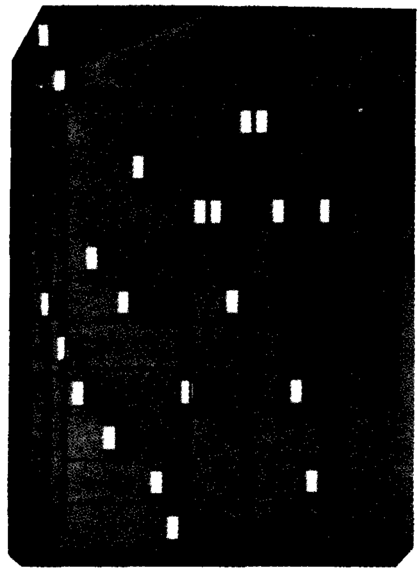


FIGURE 14-14b. PLASTIC CARD

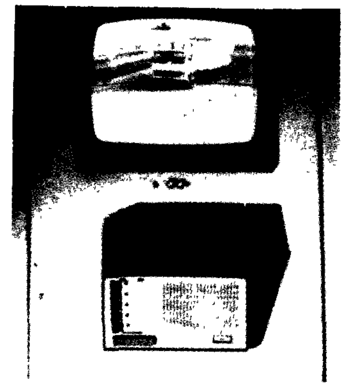


FIGURE 14-14c. MONITOR IN CONTROL ROOM OF TRUCK SCALE

FIGURE 14-14d. DIGITAL READOUT IN SCALE HOUSE

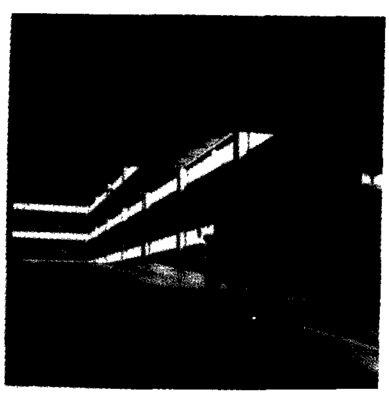


FIGURE 14-14e. RAMP TO TIPPING FLOOR

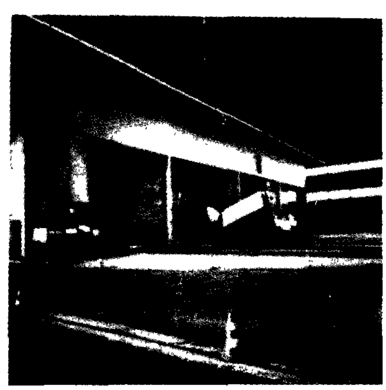


FIGURE 14-14f. TIPPING FLOOR

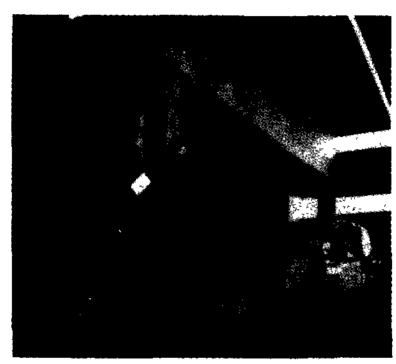


FIGURE 14-14g. TIP ARRANGEMENT PERMITTING GOOD CRANE VIEW

Occasionally the plastic cards jam, break, or become lost. In this event, the driver would have to get out of the truck and spend several minutes in the scale house filling out a form. The cards were replaced on an as-needed basis. They have changed the system so that every 6 months all of the plastic cards are changed at once.

At the time of the visit in October, 1977, a particular card would work at Amager, West, and the Hillerod transfer station. An identical Philips system was under consideration for the Roskilde Volund plant as well. In theory, the system could be used throughout Denmark to the advantage of all.

Relevant information is displayed (see Figure 14-14d) on digital readout devices. The single operator can process 120 vehicles per hour if both scales are used simultaneously. The scales can be used automatically at night when the scale house is unmanned. Opening the plant gate and weighing the vehicles can be controlled from inside the plant at the main control room with use of television cameras (see Figure 14-14c). Truck entrance and tipping activities are shown in Figures 14-14e, f, and g.

Waste Storage and Retrieval

Amager has a pit 48 m (158 ft) long, 17 m (56 ft) wide, and 13 m (43 ft) deep. The capacity to the tipping floor door level is 10,000 m^3 (13,462 yd^3). However, with refuse piled against several doors and by piling refuse against the wall to the furnace, the maximum capacity can be doubled to 20,000 m^3 26,924 yd^3). This converts to 3.5 days maximum storage. The specific weight or density is 0.2 to 0.3 tonnes/m^3 (336 to 505 pounds/yd^3).

The 11 refuse doors are described as double hinged flap doors 8.0 m (26.4 ft) high, 3.8 m (12.5 ft) wide, and 122 mm (4.8 in) thick. They are operated hydraulically. The tipping configuration was designed carefully to allow for a door and also to permit full view of tipped refuse by the crane operators (see Figures 14-15a and b).

The West pit is much deeper by comparison than Amager. The West pit bottom is 4.0 m (13.2 ft) above sea level while Amager is 3.7 m (12.2ft) below sea level.

There are two fire cannons located around the pit at the hopper level. They also have four hoses that are 30 m (100 ft) long. The local fire department is called for the few fires that cannot be controlled by plant personnel.

The plant has two cranes (one active and one often in reserve), manufactured by Thomas Schmidt A/S. During the day, the second crane mixes incoming waste to a fairly uniform calorific content. Only at night is this crane truly in reserve.

Comment: When planning the number of cranes, there are a number of factors that could necessitate having a mixing crane. Some are seasonal changes with low calorific value (wet vegetation loads), a or high calorific material (truck loads of tires, industrial plastics etc.). If in the future, industrial wastes might augment household waste, space should be set aside during the initial construction for a mixing crane.

Each crane is rated at 10.5 tonnes (11.5 tons). Television cameras aimed at the hopper assist the crane operator in setting the drop position over the hopper.

When both cranes are functioning, they can together put up to 50 tonnes (55 tons) per hour into hoppers. The cranes are equipped with Sven 8 m^3 (10.8 yd^3) star grab polyp buckets (Figure 14-16a). Each normally handles 2.5 tonnes (2.75 tons) of refuse per lift. The maximum net load is 4 tonnes (4.4 tons).

The Amager cranes were initially a source of numerous problems. Esentially the cranes and bucket were undersized. The bearings on the polyp bucket often failed. The crane hoist motor would burn out for no apparent reason. Hydraulic leaks from the polyp due to high temperatures on the hydraulic coil were frequent.

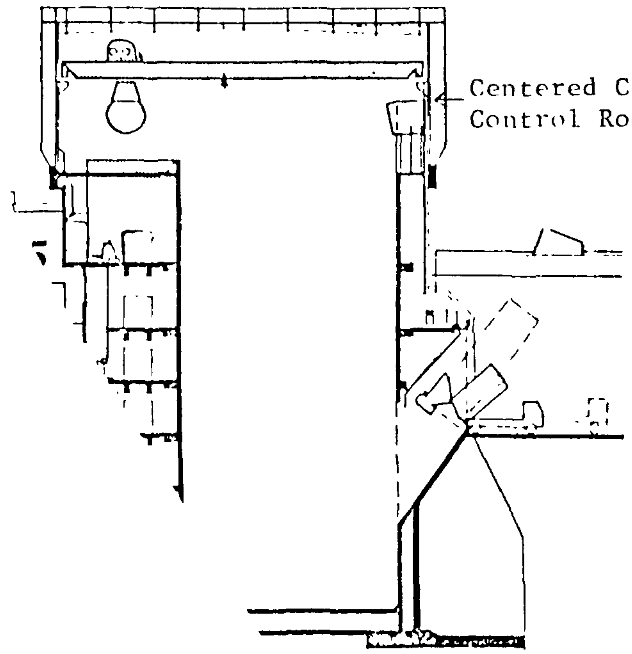


FIGURE 14-15a. TIPPING DOOR THAT CAN CLOSE. UNOBSTRUCTED VIEW OF PIT BY CRANE OPERATOR

FIGURE 14-15b. CRANE OPERATOR CONTROLLING POLYP TOWARDS HOPPER

FIGURE 14-16a. SVEN POLYP GRAB AT COPENHAGEN:AMAGER GOING DOWN FOR ANOTHER LOAD

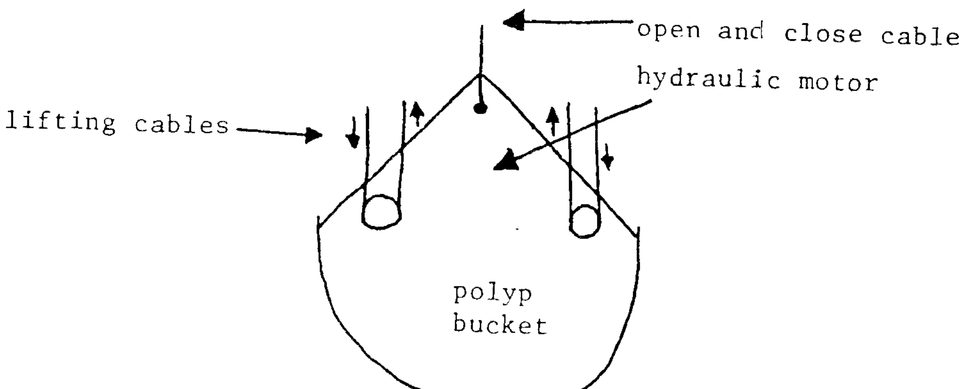


FIGURE 14-16b. SCHEMATIC OF POLYP

After 2 years, most of the problems were solved by a series of corrective steps. Bearings twice the original size were installed. The German electric motors were replaced by larger Siemensmotors. Better seal packing and gaskets reduced hydraulic oil leakage.

However, the original design did have beneficial features. In contrast to the old Gentofte plant where cables would break every 2 weeks, the Amager cables would last about 1 year. The difference was for several reasons. First, a strong special German wire cable was always used. Second, the bucket was always hydraulic and not mechanical. Third, the polyp is controlled with a hydraulic motor located inside the bell of the polyp top. There is a sensor so that when the polyp is more than 45 degrees from its level position, it switches off and refuses to permit further movement that might snag the cables. Fourth, the polyp has additional stability due to the four lifting strands as compared to two strands in some less expensive system as shown in Figure 14-16b.

Based on the many crane problems at Amager and the success in curing them, West was more properly designed and has had fewer problems. This revised cable and polyp system has worked exceptionally well and is considered well worth the extra money. Incidentally, Volund was so impressed with the Sven polyp that Volund bought Sven in 1977.

Furnace Hoppers, Feeders, and Swivel Gate

The hopper dimensions at its top opening are 6 m (20 ft) by 6 m (20 ft). Farther down, at the hopper bottom, the dimensions are 2.3 m (7.6 ft) by 1.15 m (3.8 ft). Its height is 6 m (20 ft). The walls are made from 8 mm (.31 in) plain carbon steel.

Sometimes instead of a steel hopper, Volund will install a concrete hopper. Concrete is cheaper and quieter.

The filling chute has a slightly larger width dimension than the hopper: 2.3 m (7.6 ft) by 1.15 m (3.8 ft). It too is made of 8 mm (.31 in) steel.

The swivel gate or damper is located in the chute. It is opened when refuse falls on it and closed when no refuse is above it. Its function is to prevent burnback.

The damper's dimensions are 2.58 m (8.5 ft) by 1.26 m (4.16 ft) and is 10 mm (.39 in) thick. The 2.3 m dimension gradually increases to 2.7 m (8.9 Ft) near the furnace entrance so that jamming is minimized.

Volund typically installs chutes with only refractory lining. Except for flowing material, the hopper should always be empty. There should be no refuse above this kind of damper to interfere with its closing. With proper crane operator training and performance, burnback can be minimized. Officials believe that water cooled jackets, besides being unnecessary, have more costs of operation and maintenance.

Primary (Underfire) Air

The plant designers had been of the opinion that the air intake should be at the hopper level for better control of odors from the pit. As someone stated, "if the primary air is taken from the top of the bunker (higher and above the crane), you could smell the air on the tipping crane control room-hopper floor".

The intake was thus located at the hopper level as shown in Figure 14-17. This resulted in a very dusty floor and atmosphere around the hopper. But more important the dust raised by the falling refuse would clog the vent and accumulate in the ductwork. The air intake was later raised about 3 m (10 ft) to the level shown in Figure 14-18. The entrance at this higher position should (1) better remove smoke from any pit fires (2) provide better ventilation in the summer, (3) be freer from dust and (4) permit a better environment.

The air is then pulled in and down by the Nordisk 1490 rpm fan which can pull 45,000 Nm^3/hour. The temperature is assumed to be 30 C (86 F) in the summer. The static pressure is 230 mm water.

Primary air is delivered to four hoppers under the grates: Drying Grate (one hopper), Ignition Grate (one hopper), and the Combustion Grate (two hoppers). There is one large damper per furnace that is set only once. However, each of the four hoppers (plemum sections) has its own separately controlled damper that can be adjusted from the control room. Each hopper's pressure reading is sent to the control room, but it is not recorded.

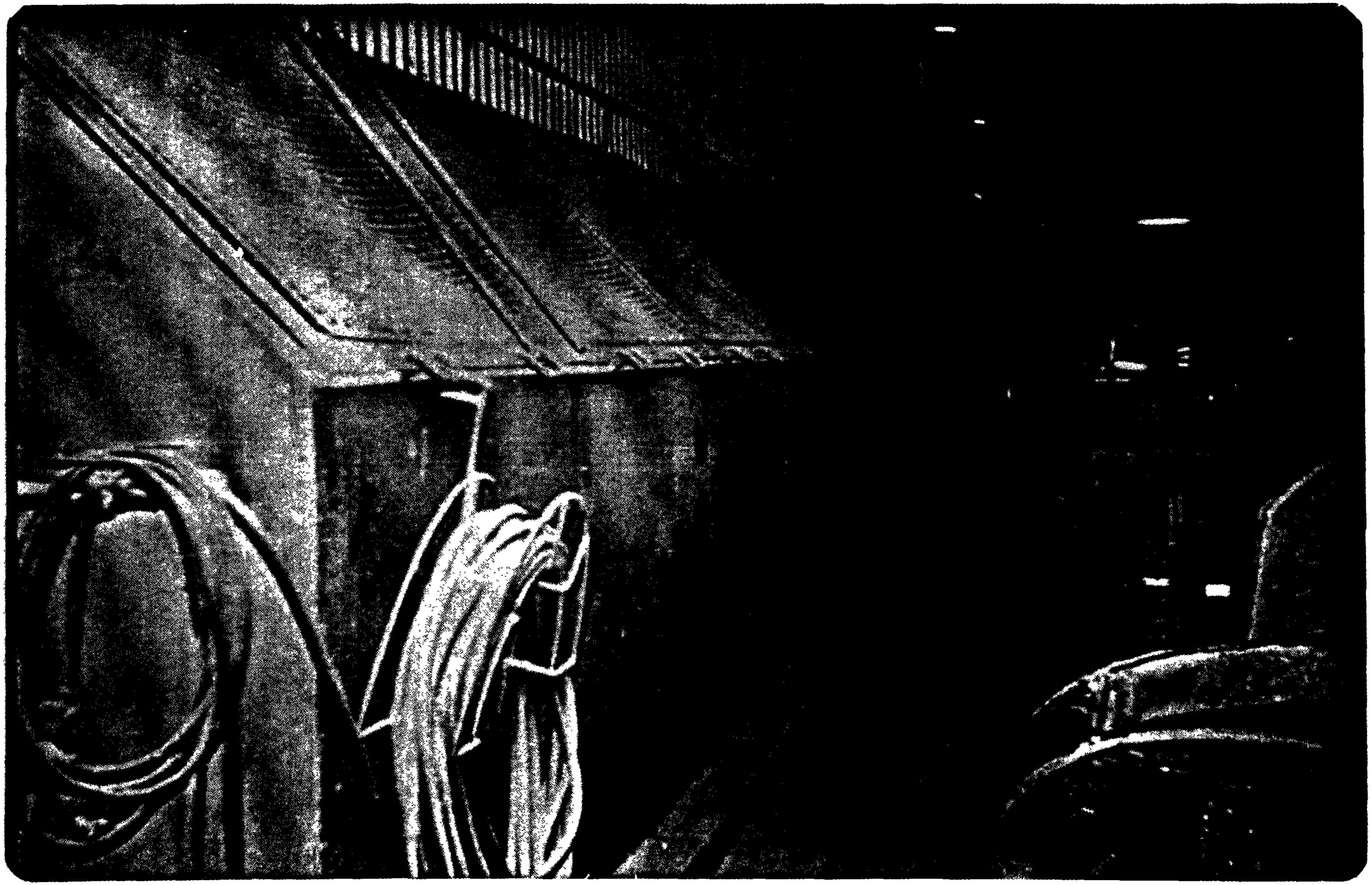


FIGURE 14-17 SLOPING AIR INTAKE FILTERS ABOVE THE BUNKER AT COPENHAGEN:WEST ONLY (RAISED INTAKES AT AMAGER)

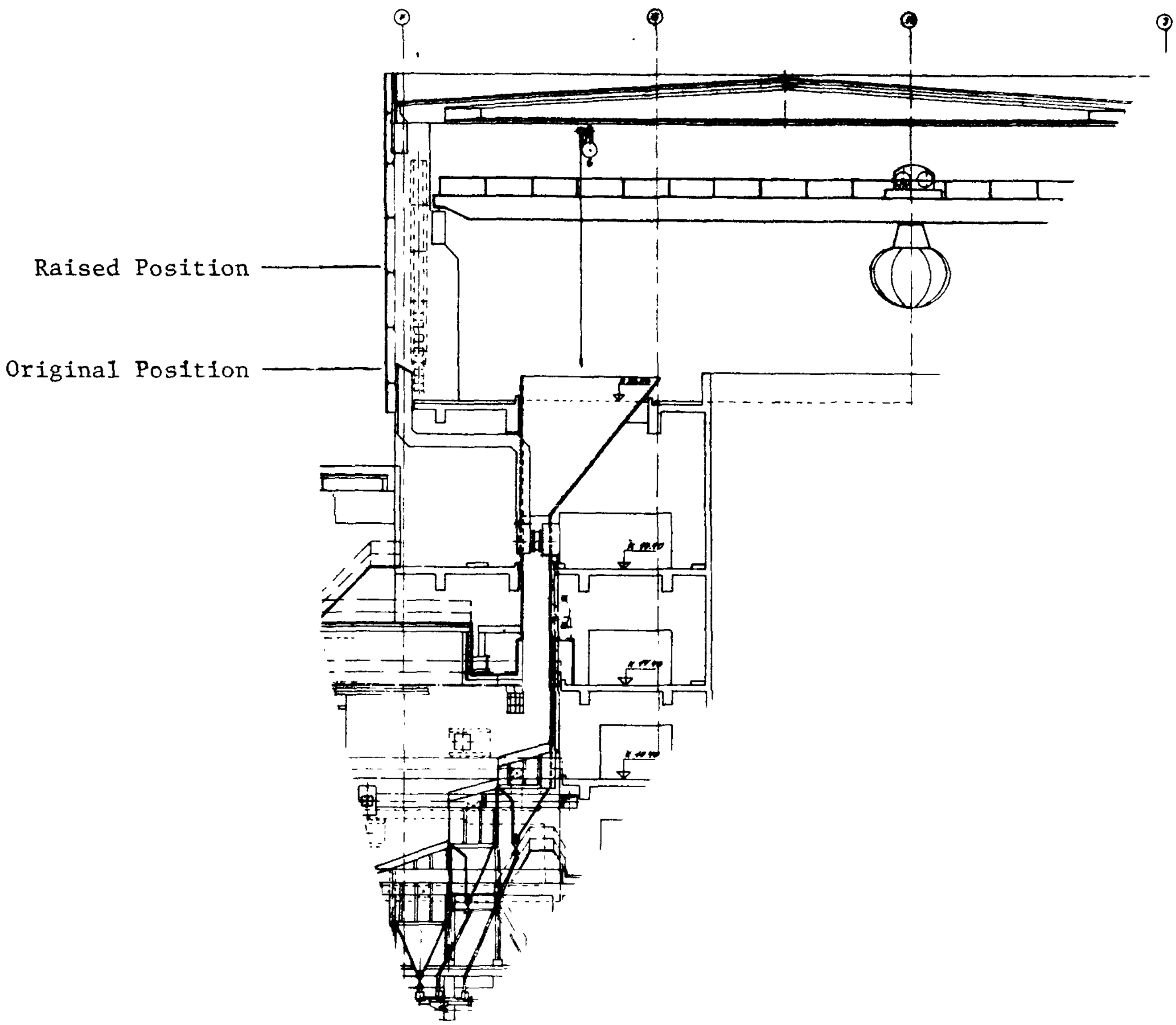


FIGURE 14-18. ORIGINAL AND RAISED POSITION OF THE PRIMARY AIR INTAKE

There are two types of fan drives available for designs: (1) fan belt and (2) direct. The direct method is not normally used except for large induced draft (ID) fans just before the chimney. In the future, the Amager plant capacity can be raised (other systems permitting) simply by changing the belt. Assuming that the electric motor speed does not change, then the air pressure can be lowered and a higher quantity of air can be passed.

Volund usually specifies a fan to be operated at a point situated in the middle of the capacity curve e.g. lower r.p.m. than the maximum allowed. In case more air is necessary, for speed can be increased.

One other point is that when Volund dimensions a fan they ask for a certain amount of air at a certain pressure. In case the pressure is lower than necessary more air can be transported by the fan. These two factors are proportionally to each other e.g. higher pressure = less air.

There are now very few problems with the primary air system. The blades are self cleaning. Sometimes when the hopper floor area is hosed down with water, the mist would be sucked into the vent. The moisture would mix with the dust (from crane discharges into the hopper) and form deposits. Now every 6 months, the ventilator is opened and air is blown through the duct.

Secondary (Overfire) Air

Volund furnaces have three (3) sources of secondary air that can be blended for proper operation. Sometimes (1) oxygen rich refuse bunker air (2) normal boiler room air or (3) oxygen poor flue gas recirculation air may be needed in varying amounts when the refuse heating content varies.

Refuse Bunker-Oxygen Rich Air

Amager can pull its cool oxygen-rich secondary air from the refuse bunker. This is slightly different from West where both primary and secondary air is pulled from the boiler room. The Nordisk Ventilator forced-draft 150 Hp belt-driven fan, running at 1,670 rpm, can pull 35,000 Nm^3 hour. The temperature is assumed to be 30 C (86 F) and the static pressure is 460 mm water.

The air is sent to two manifolds on each side of the furnace and above Grate III. Each manifold a set of nozzles as shown below.

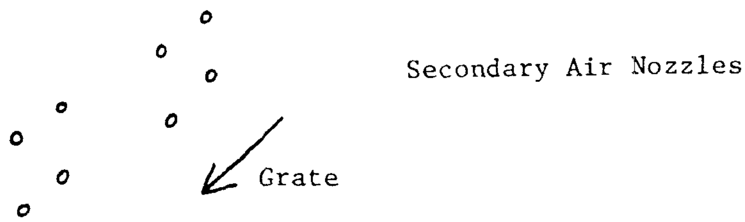


Figure 14-19 shows the sidewall jets.

Flue Gas Recirculation - Oxygen Poor Air

Amager formerly (during only the first year) used recirculated flue gas as secondary air. The air was drawn from the flue gas leaving the hot electrostatic precipitator. See the previous Figure 14-1.

Another Nordisk Ventilator forced draft fan, this one at 150 Hp, was belt driven at 1,460 rpm. The fan is rated at 45,000 Nm^3/hour and delivered the 300 to 350 C (572 to 662 F) hot flue gas at 220 mm water pressure.

Many Volund units are built to permit use of either or to permit blending.

Boiler Room - Oxygen Normal Air

The use of ambient boiler room air at 30 C (86 F) or recirculated flue gas air, 138 to 177 C (280 to 350 F), is determined by basic furnace design and the refuse lower heating value (LHV). Assume that the furnaces were nominally designed for refuse with a LHV of 2,000 kcal/kg. If the LHV is well over 2,500 kcal/kg, air rich in O_2, might shock the refractory and cause the Carborundum bricks to grow and then spall. Therefore, if the refuse is "hot", then recirculated flue gas air, poorer in O_2, should be used. In contrast, if the refuse is "cool" or wet, then ambient boiler room, rich in O_2, should be used.

Of the European vendors visited, Volund is the only manufacturer known to us to use recirculated flue gas.

FIGURE 14-19. SIX DILUTION SIDEWALL SECONDARY OVERFIRE AIR JETS AT COPENHAGEN:AMAGER

The recirculation flue gas fan has a damper that is automatically controlled. It sends a larger or smaller quantity of the flue gas back to the furnace depending on the furnace combustion temperature. The dampers are adjusted so that the furnace temperature is always 900 to 1,000 C (1652 to 1832 F).

At Amager, where the refuse is cooler, 1,800 kcal/kg (3240 Btu/pound), than at West, they now use both refuse bunker primary air and boiler room secondary air. Refractory life has improved. The boiler room air is now put through the back wall where the flue gas recirculation air had been previously inserted.

Flue Gas Fan

An induced-draft Nordisk Ventilator flue-gas fan is located between the electrostatic precipitator and the chimney. It is necessarily the strongest fan and can pull 107,000 Nm^3/hour with its 220 Hp motor. It too is belt driven but at a lower speed of 1010 rpm. It delivers the flue gas at 170mm water pressure to the chimney. Flue gas temperatures range from 300 to 350 C (572 to 622 F). The fan has a damper connected with a regulator which holds the vacuum in the furnace constant at all times.

Fan Summary

Table 14-2 presents key design parameters for the four fans: (1) F.D. primary air, (2) F.D. secondary air, (3) I.D. flue gas recirculation, and (4) F.D. flue gas recirculation.

The plant people report that the furnaces each with four fans have experienced only minor maintenance.

Assuming the maximum refuse calorific value to be 2,500 kcal/kg (4500 Btu/pound), the theoretical air is 3.01 m^3/kg (234 ft^3/pound). After combustion, the theoretical combustion flue gas is 3.78 m^3/kg (294 ft^3/pound), while the actual is 5.3 to 6.8 m^3/kg (412 to 528 ft^3/pound).

TABLE 14-2. PRIMARY, SECONDARY, FLUE GAS AND RECIRCULATION FAN PARAMETERS

	Primary Air Forced Draft	Secondary Air Forced Draft	Flue Gas Induced Draft	Flue Gas Recirculation *
Fans per Furnace	1	1	1	1
Volume of Air (Nm^3/hour)	45,000	35,000	107,000	45,000
Static Pressure (mm Water)	230	460	170	220
Temperature (° C)	30	30	350	350
Fan Revolutions (rpm)	1,490	1,670	1,010	1,460
Belt Driving	yes	yes	yes	yes
Motor Power (Hp)	75	150	220	150

* Flue Gas Recirculation, originally installed, is no longer used.

Furnace Combustion Chamber

The original Volund designers had two seemingly opposite design considerations. First, the design should ensure proper drying out of the wet refuse. Therefore, there is a desire to use a gas counter-flow to the waste flow as shown in Figure 14-20a.

On the other hand, there should be good burnout of putrescibles and carbon. Therefore, the gas flow should parallel the waste flow as in Figure14-20b.

A compromise suggested by other vendors would be to simply have the flue gas exit centered over the grate as shown in Figure 14-20c.

The Volund simplified answer is to put a wall above the grate and to send some of the gases back toward the feed chute and the other gases toward the ash chute as shown in Figure 14-20d.

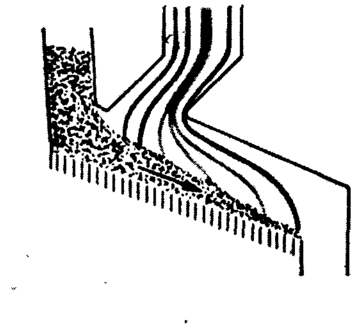
The more elaborate answer from Volund is to attach a rotary kiln at the end of the furnace grate as shown in Figure 14-20e. Here some hot gas returns back toward the feed chute to help dry the incoming waste. Also, the other gases continue flowing with the waste out of the grate area and into the rotary kiln. The heat supports further combustion in the kiln to consume almost all of the putrescibles and unburnt carbon.

This configuration, known as the two-way gas grate and rotary kiln system, is the design at both Amager and West. The schematic (see Figure 14-21) for Frederiksberg (1934) shows the basic configurations. To restate, the original two Volund plants (Gentofte and Frederiksberg) successfully served Copenhagen for 40 years.

Burning Grate (Forward Pushing Step Grate)

Information, for the record, regarding the Volund grate is distributed between the trip reports 14 and 15 (Amager and West). Part of this section is taken directly from a technical 1969 paper written by Mr. E. Blach, former Volund Chief Engineer, entitled "Plants for Incineration of Refuse".

> "This grate construction is built up of several grate sections, each separated by a vertical grate transition bar. The



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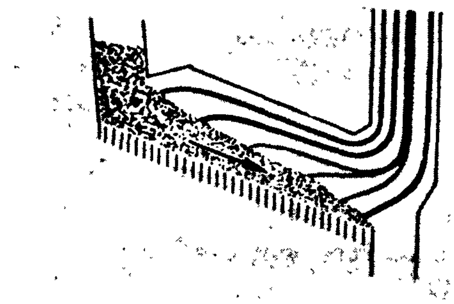

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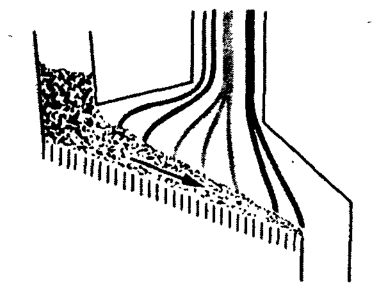

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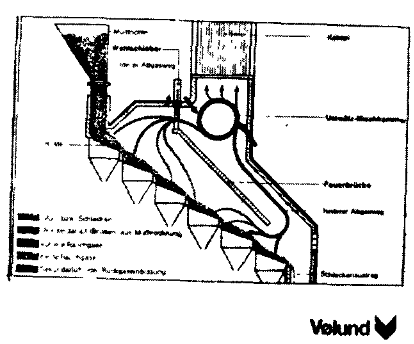

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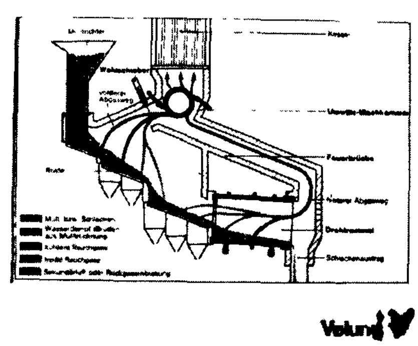

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FIGURE 14-20. GENERAL DESIGN CONFIGURATIONS FOR VOLUND FURNACES

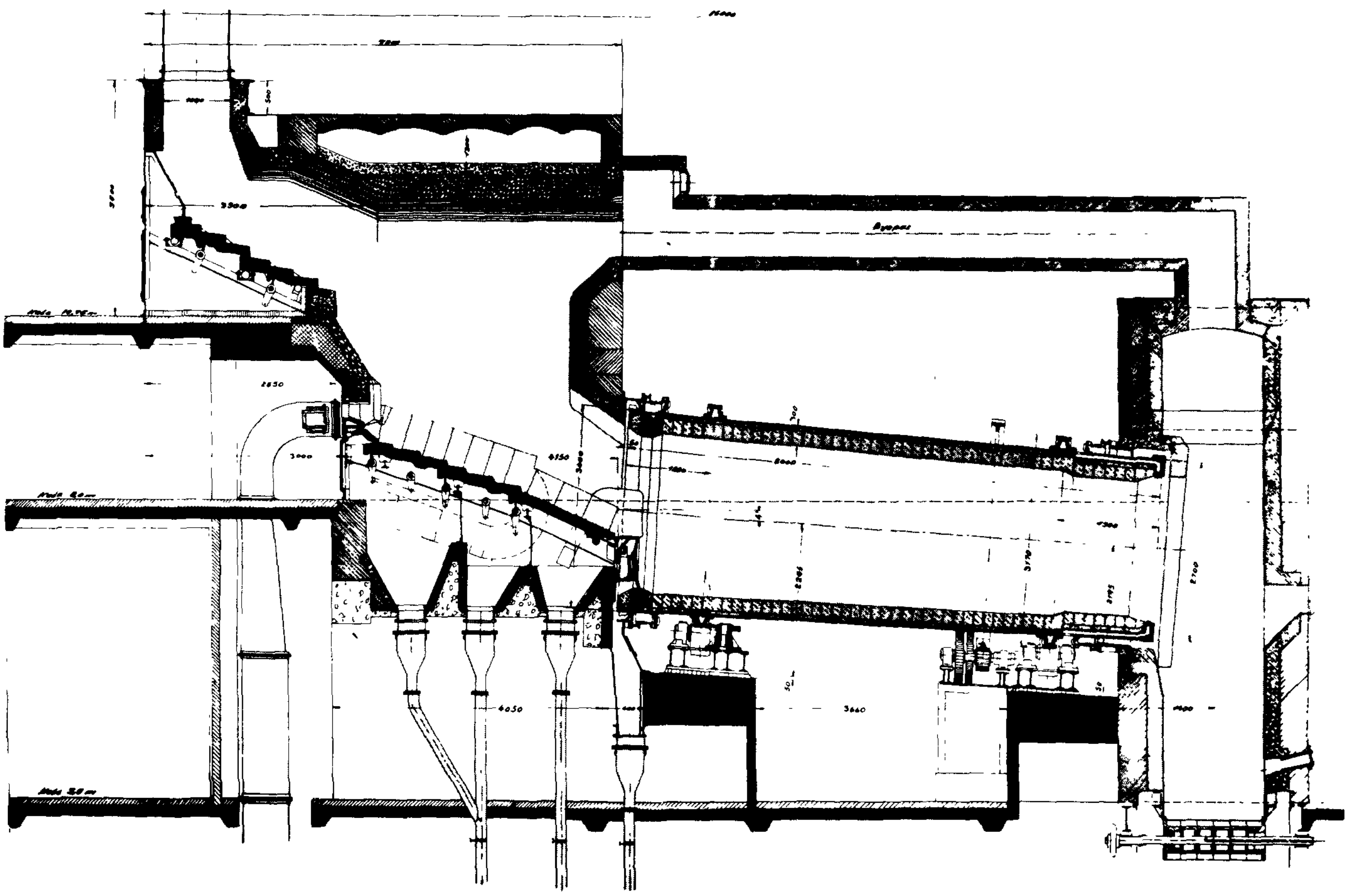


FIGURE 14-21. FURNACE DESIGN (TWO-WAY GAS GRATE AND ROTARY KILN) AT THE OLD (1934) FREDERIKSBERG PLANT, DISMANTLED IN 1970

ratio of size between the individual grate sections and grate transitions is determined by the composition of the refuse.

Figure 14-22. The individual grate section is built up of lengthwise-placed sections of 180 to 300 mm wide laid up with an inclination of 18-15°. Every other of these sections are fixed and every other are moveable, and each section is built up of a through grate bar, which is welded up, on which a number of grate blocks of specially alloyed cast iron are fitted, which are in turn filled up with loose grate bars of cast iron.

Figure 14-23. The moveable sections are driven hydraulically by a transverse driving shaft placed under the grate, which is connected to the individual sections by pendulum driving bars. From a neutral position, the movement in forwards stroke is slowly raising, forward going, and then lowering and backwards going. In the backwards stroke, the movement is slowly lowering and backwards going and then raising and forwards going.

Along the side of grate sections, which are built into the wall of the furnace, there are a number of side sealing beams, which through building in springs give the grate sections a transverse flexible assembling.

Figure 14-24 is a drawing included in one of Volund's first patents. The first grate section acts as a feeding and predrying grate and apart from the last part of the transition bar, it is covered with grate plates. Ignition and the first part of the combustion take place at the first transition and on the second grate. The final combustion and burnout takes place on the third grate, and calcining and cooling of the clinkers begin at the last part of the third grate and continue on the subsequent clinker chute.

The layer of refuse is 300 to 500 mm (12 to 20 inches). The moveable grate sections give a lifting, moving, and turning movement in the lower half of the layer so that the combustion air, which in a regulated way is supplied from below, can get to all parts of the layer. At the transition bars, there is a supplementary turning, mixing, and air supply.

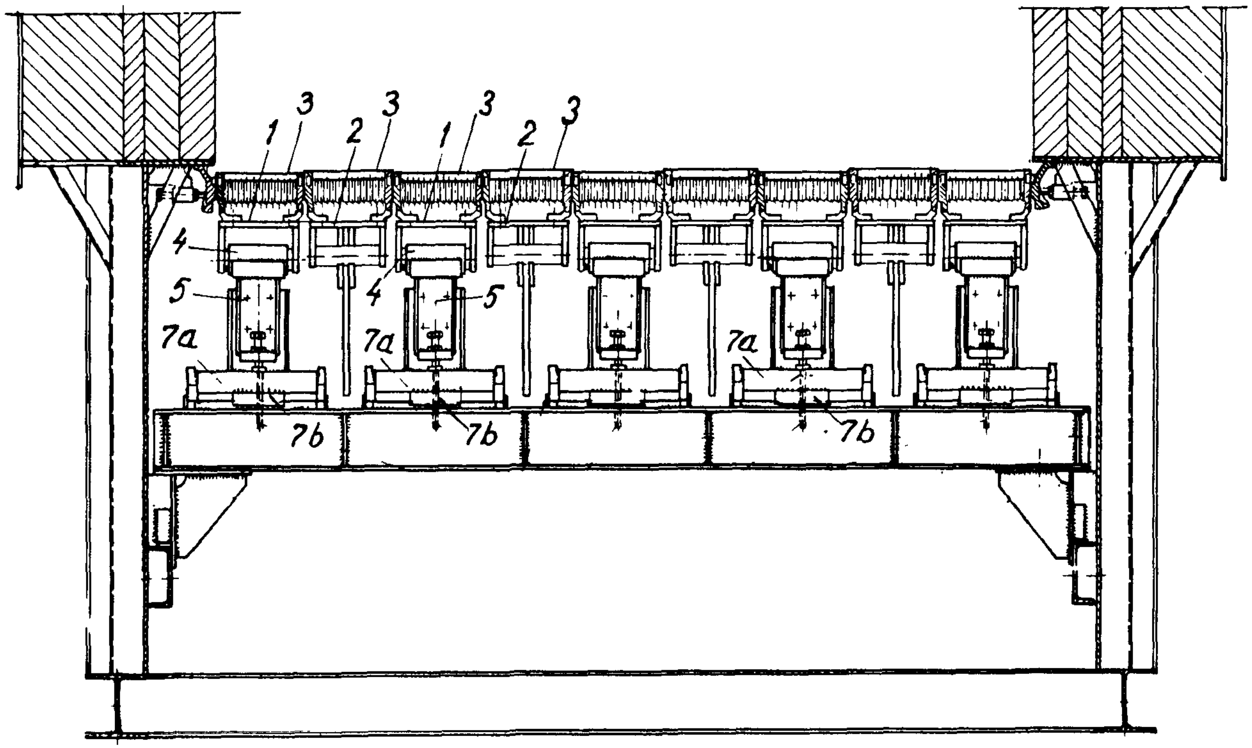


FIGURE 14-22. VOLUND'S LENGTHWISE PLACED SECTION OF GRATE

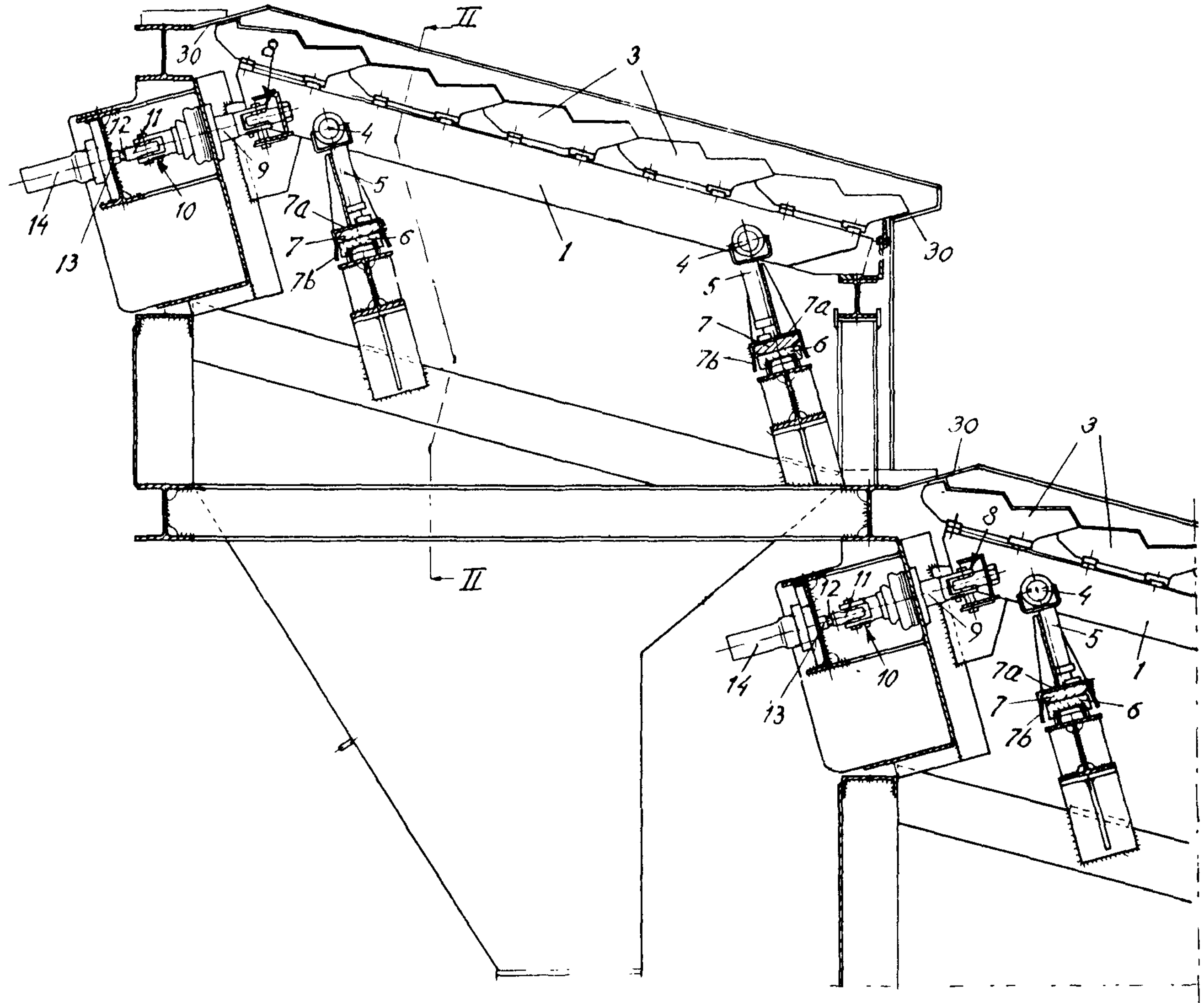
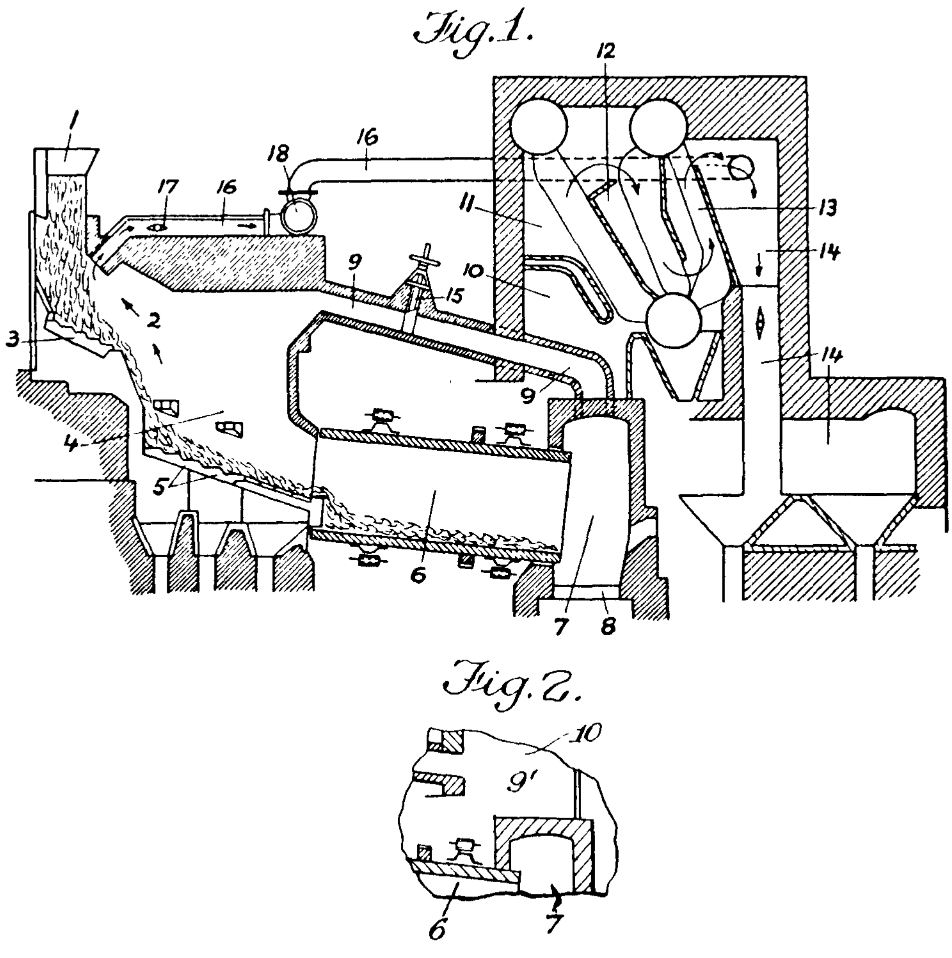


FIGURE 14-23. VOLUND'S MOVABLE SECTIONS HYDRAULICALLY DRIVEN BY A TRANSVERSE DRIVING SHAFT CONNECTED TO THE INDIVIDUAL SECTIONS BY PENDULUM DRIVING BARS

Oct. 1, 1935. A. CHRISTENSEN **2,015,842**

FURNACE WITH GRATE FOR COMBUSTION OF REFUSE OF ANY KIND

Filed Nov. 5, 1932



INVENTOR
AAGE CHRISTENSEN

FIGURE 14-24. ONE OF THE EARLIEST VOLUND PATENTS

Volund supplies furnaces with either three or four separate grates. Amager has three grates per furnace.

Each of the furnaces has two operating hydraulic pumps. At some other installations, an additional hydraulic pump is used as a standby. Each pump's capacity is 47 liters/minute (12.4 gallons/minute). Each pump has a 15 Hp motor. The resultant pressure is 70 kg/cm^2 (1,160 pounds/in^2). The plant has one 600 liter (160 gallon) hydraulic oil storage tank.

Each of the first three grates have five hydraulic cylinders with cylinder bases of 80 mm (3.15 inches) and strokes of 130 mm (5.1inches). The stroke frequency is three strokes per minute.

Having three grates means that there are two steps. The height between Drying Grate I and Grate II is 1 m (3 feet). Between Grate II and Final Grate III, the height is 2 m (6 feet).

The final step, from the grate system to the rotary kiln, is 1 m (3 feet) high. The grate exit to the rotary kiln is shown in Figure 14-25.

The earlier Volund plants (1930's) had grates with an angle of 23 degrees and a conical rotary kiln based on the refuse composition of the "poor times". In the beginning of 1960 the grate inclination was 20 degrees and the kiln at a choice of conical or cylinder depending on the town and the living standard of people.

In 1965 the rotary kiln became cylindrical and the grates were constructed at 15 degrees. This is the present situation.

Amager plant officials estimate that the individual grate bars will last about 15,000 hours. Stated in another manner, on the average 100 percent of the bars are replaced every 15,000 hours. The grate bars last 20,000 hours at West.

Compared to West, the amount of small-sized inert (ash) particles is more at Amager. Perhaps Amager's increased volume of inerts, less grass and more home furnace ash, contribute to Amager's shorter grate life.

The ash leaving the Amager plant is often smaller than the West ash because any large clinker at 800 C (1472 F) from the rotary kiln falling into a bath of "cold" water will explode into small fragments.

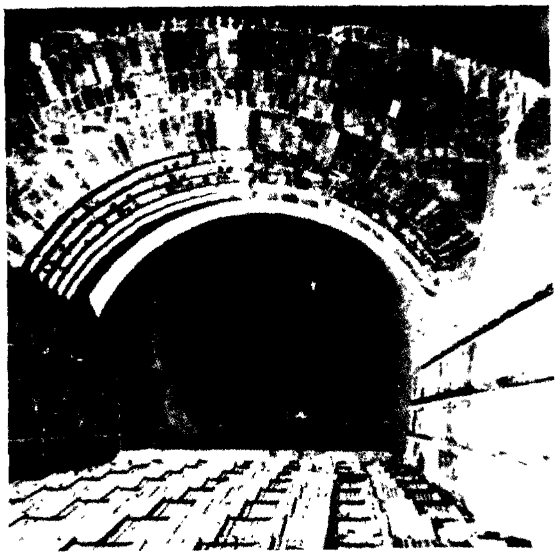


FIGURE 14-25. GRATE FURNACE EXIT INTO A ROTARY KILN AT ONE OF VOLUND'S PLANTS

All grate frames, bars, and grates are made from a material called "Meehanite HR." It is ductile but has a minimum 350 Brinnell hardness. The side seals are made from "Nicromax". Due to the moving and rubbing surfaces, this can be less ductile but very hard. Occasionally tramp metal (usually iron) will fall on the first grate and break a bar.

All three grates have a 2.7 m (8.9 feet) width. The grate stroke is 130 mm (5.1 inches). Roughly 23 percent of the grate area is open for combustion air to enter. The length and area of the three grates are as follows:

	Drying Grate 1	Burning Grate 2	Burning Grate 3
Grate Length (m)	2.5	2.0	5.0
Area (m^2)	6.75	5.4	13.5

Furnace Refractory Wall

Volund furnace walls are refractory lined (and not lined with water tube walls) inside a steel framework.

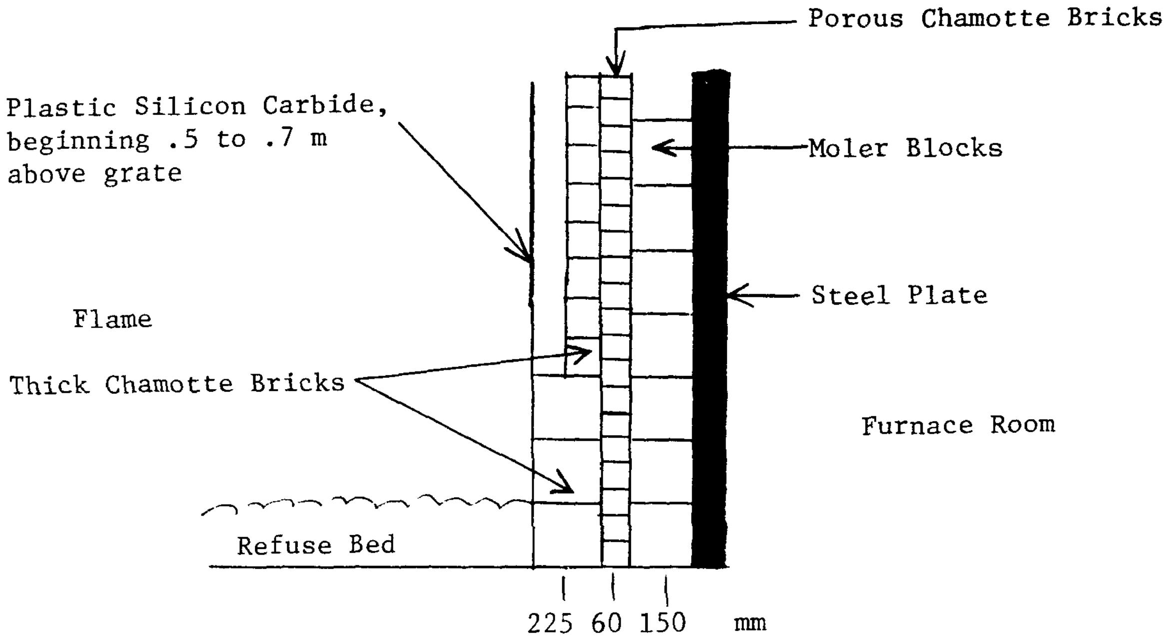
The six furnaces for both Amager and West (three each) were designed and built at about the same time. (West later added a fourth unit).

Volund originally chose Hoganus, a high-quality and expensive refractory, for its flame wall lining. The bricks themselves were not a problem. The difficulty, however, was that there were not enough anchors between the iron structural framework and the bricks. In addition, the few original anchors were not properly welded and broke during thermal expansion. Also, ash was accumulating or "slagging" on the walls.

As a result of the several problems, the furnace walls were rebuilt. Fortunately the warranty period was still in effect. More anchors were added. The welding technique was changed.

To cure the ash slagging problem, silicon carbide was added to the walls above the grate .5 to .7 m (1.5 to 2 feet). However, where the flame is hottest and the O_2 levels the greatest, the SiC is to be avoided so that it does not oxidize. Hence, the lowest wall areas and up a little bit in the middle side wall are left with Hoganus chamotte bricks exposed.

Volund officials believe that, with proper anchoring, a refractory wall furnace is less expensive and more reliable than a water tube wall furnace. Having learned from the Amager experience, they now specify a wall shown below:



The Moler blocks near the outside wall are unique to Denmark. The clay is literally quarried or carved out of the deposit in the final shape. (There is no normal mixing and blending of clays.) The blocks are simply fired. The brick dimensions of 23.4 x 11.3 x 6.2 cm (9.2 x 4.4 x 2.4 inches) weigh 1.2 kg (2.6 pounds). This is slightly heavier than many insulating fire bricks but much stronger.

Volund does not report the furnace volume or heat release area since the wall enclosures are not designed for heat transfer, as are the walls of a water-tube wall furnace.

The furnace roof is always arched if the span is less than 3 m (10 feet). However, for wider roof sections, a steel structure is built with many hangers. Specially shaped chamotte bricks are then suspended from the anchors. Then granulated Moler particles are spread on top of the steel and bricks. Finally, rock wool is laid on top of everything.

Rotary Kiln

The rotary kiln is seen in its relationship to other key furnace parts in a plant schematic of the now dismantled Gentofte plant (see the previous Figure 14-7) that served northern Copenhagen so well for 40 years. The basic design (with the exception of major modifications to the boiler and air pollution control equipment) remains the same today. To repeat, again from Mr. E. Blach's paper:

> "Pre-drying, ignition, and the first part of the combustion takes place on the grate system ..., but then the refuse slides into the rotary kiln, where the final combustion and burning out takes place.
>
> While in operation the rotary kiln turns slowly and thus creates a perfect overturning of the burning refuse. The movement makes the refuse travel a very long way and thereby stay for a long time in the kiln. The system operates with the so-called divided flue gas/combustion air circulation, e.g. the primary combustion air is divided into two after having passed through the layer of refuse on the grates, one part passing through the rotary kiln and one part passing over the layer of refuse on the grates up to the top of the furnace, from where it is brought back to the after burning chamber through the previously mentioned connecting flue gas passage coming from the rotary kiln.
>
> Besides primary air, secondary air is added over the grate sections as well as the rotary kiln in order to ensure for certain that the flue gases are fully burned. By adding a surplus of primary and/or secondary air a cooling of the combustion can be achieved. But this cooling function can be achieved better and more effectively by using a flue gas recirculation system, e.g., cooled flue gas is brought back to the combustion zone, over the grates, and at the rotary kiln. While in operation, this cooling function is done automatically so that the temperature is kept at 900°- 1,000° C.

The rotary kiln is built up of an outer heavy steel plate, which are lined with wear resistant fire-proof bricks on the inside laid up and built on an insulating layer direct up to the steel plate. The ends the kiln are furnished with special sliding seals and transition sections. The whole construction rests on two sets of running and guiding wheels, which at the same time act as friction pinion, activated by hydraulic motors. The speed of rotation can be regulated variably between 0 and 15 r.p.h.

The grate/rotary kiln design is used for capacities from 5 t/h to about 20 t/h, but can be built also in larger plants."

The carbon steel shell (see Figure 14-26) has an inside diameter of 4 m (13.2 feet). With the addition of refractory, the inside diameter is reduced to 3.4 m (11.2 feet). Each kiln is 8 m (26.4 feet) long. Volund will build kilns up to 10 m (33 feet). The volume is 73 m^2

The kiln is sloped downward at a 3 degree angle and revolves upwards of 12 revolutions per hour (rph). It however, normally revolves at 6 to 8 rph. If the furnace operator is told by the crane operator that the refuse is wet or if he sees a disturbance in the kiln, he can easily lower the kiln speed.

The original configuration had two support rings, two support rollers, one thrust roller, and two drive support rollers all made from high tensile-strength steel castings (see Figure 14-27).

Later, officials decided that large spacing between rollers was permitting alternatively excessive compressive and tensile forces. Thus open spaces would develop in the lining depending on where the brick section was on its rotation. Eventually bricks would be either crushed or would fall out.

The two hydraulic motors per kiln are rated at 3 kg-m (21.8 foot-pounds) and have a maximum speed of 76 revolutions per hour or 1.27 rpm. The nominal reduction is 1:800.

The refractory bricks are anchored onto the steel shell. Moler refractory was originally specified to be placed next to the steel shell. Then next to the Moler refractory, Chamotte bricks of 36-55 percent Al_2O_3 content are used to line the inside of the kiln. The composition is 85 percent SiC at the inlet.

FIGURE 14-26. ROTARY KILN BEING REPAIRED
AT COPENHAGEN: AMAGER

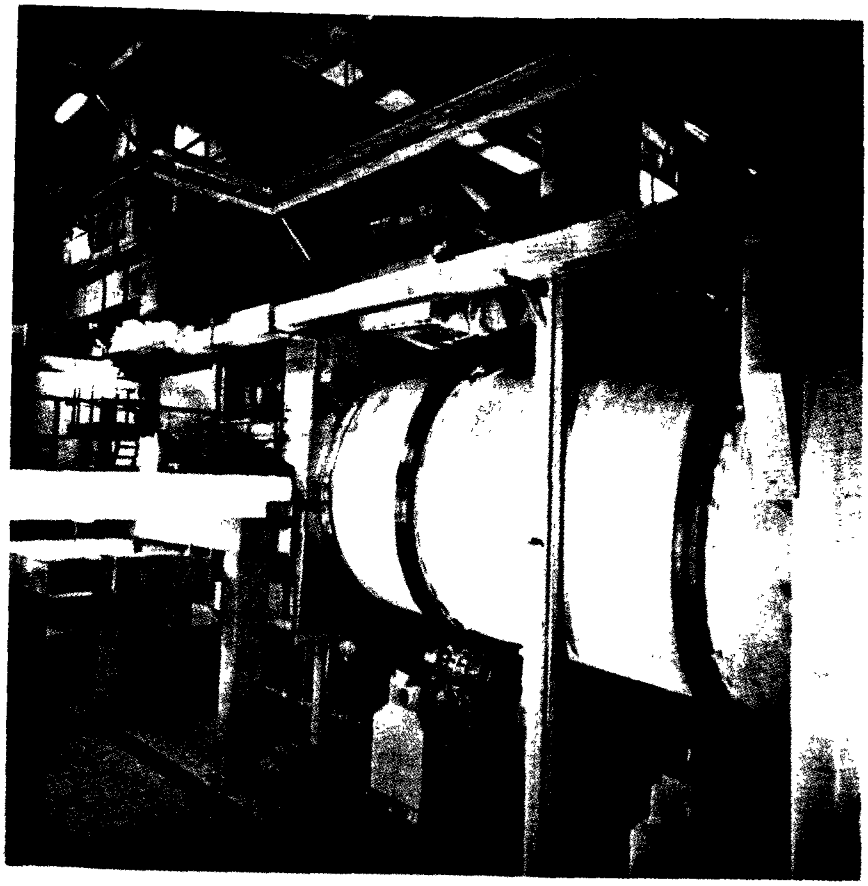


FIGURE 14-27. TWO SUPPORT RINGS OF A VOLUND ROTARY KILN

To some extent, because of very high temperatures, the kiln is self-cleaning. Slag does not normally accumulate on refractory walls. However, at some other Volund plants, slag "rings" occasionally form within the kiln. This only occurs if the kiln is conical and the temperature is very high. Interestingly, this slag ring can gradually move down the length of the kiln. It eventually disappears.

Everytime the furnace is stopped and cooled enough , the kiln is inspected. Occasionally several rings of brick are replaced. Finally in 1977, after 7 year's (42,000 hours) operation, the kiln was completely rebuilt at a cost of 150,000 D.kr. ($25,960).

During this major change, the brick used was respecified. Instead of the very porous Moler brick, which was crushed under compressive pressures once per revolution, a harder inner brick was used. Some insulation quality was sacrificed but the temperature just outside the kiln rose only 2 C (3.6 F) from before.

After Burning Chamber

Flue gas leaves both the grate section in an upward direction while flue gas also leaves the kiln and rises. Occasionally slag will form on the 45^{o} slanting lower surface in the mixing chamber above the rotating kiln (see Figure 14-1).

Boiler (General)

The boilers at both Amager and West were designed and built under Volund patents. The Amager units consist of a refractory walled furnace, an afterburning chamber and then followed by the Volund boiler (see Figure 14-28). Thus, Volund units are not "water wall incinerators."

Later Volund plants in Japan and Aalborg have Eckrohr vertical water-tube wall boilers completely separate and following the combustion furnace. The Eckrohr (translated "corner-tube") boilers were built under a license from Professor Dr. Vorkauf of Berlin, W. Germany. We later heard that roughly 180 of these boilers have been installed on refuse-fired energy systems. When asked why Volund often now uses the Eckrohr boiler instead of the traditional Volund boiler, the reply evoked the Eckrohr features - features that seemed popular in several other places over Europe.

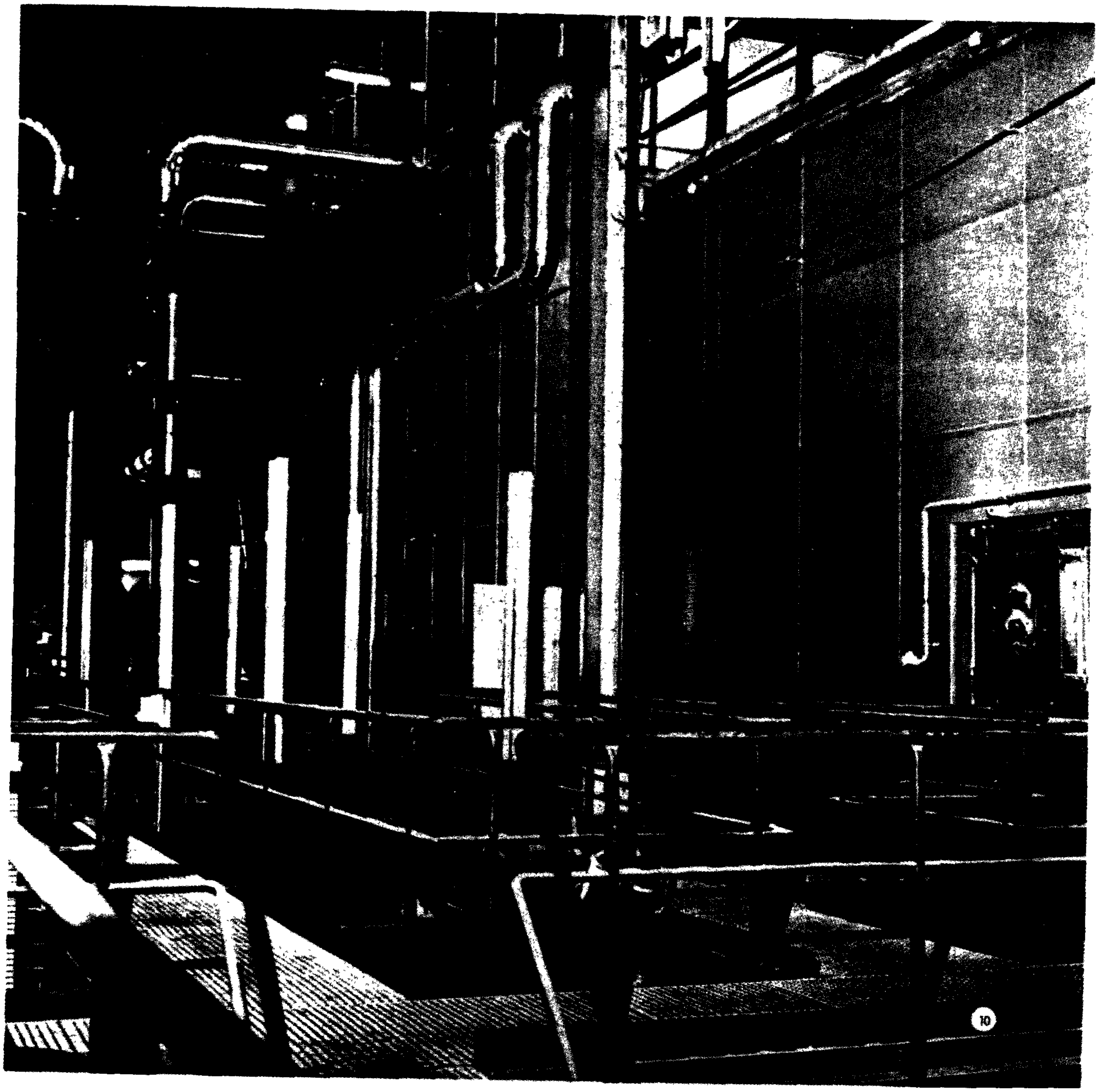


FIGURE 14-28. AFTER BURNING CHAMBER AND BOILER AT COPENHAGEN: AMAGER

- The four corner tubes are used not only to carry downstream water but also they provide structural support for the whole boiler, thus reducing construction costs.
- The heat transfers rate is excellent.
- The circulation pattern is good.
- It has high efficiency.
- It is a natural circulation boiler.

The market for energy demands slightly higher temperatures at West than at Amager as follows:

	West	Amager
Energy form	Overheated water	hot water
Water temperature leaving plant*	160 - 170 C	115 - 120 C
Water temperature returning to plant*	140 C	70 - 75 C
	284 F	158 F
Heat output	21.5 gcal/hour	20 gcal/hour
Pressure (working)	16 kg/cm^2	6 kg/cm^2 - 7 kg/cm^2
	225 psi	85 psi

The key reason for higher temperatures at West (and not Amager) is that an early customer was the Copenhagen County Hospital that needed hotter water for sterilization and air conditioning. So often, we have observed that the initial customers will dominantly effect long term energy configurations.

The amount of combustion gas entering the boiler was provided but as a function of refuse lower heating values.

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* Actual temperatures will vary from these average temperatures depending on the time of year.

	Lower Heating Value, kcal/kg	Amount of Gas, Nm^3/hour
Lowest	1,000	33,000
Average	2,000	77,000
Highest	2,500	98,500

The combustion gas inlet temperature to the boiler is around 800 C (1,472 F). The outlet combustion gas temperatures range from 280 to 350 C (536 to 662 F).

Details of heating surface area are shown below with the codes also appearing in Figure 14-29:

	Units 1-3
First Pass Radiation Wall (R1)	115 m^2
Second Pass Radiation Wall (R2)	99
Third Pass Radiation Wall (R3)	87
Regular Radiation Walls	301
Scott Walls (S1 and S2)	29
Total Radiation Walls	330
Convection Section (C)	330
Economizer Section (E)	455
Total Heating Area	1,115 m^2

Boiler cleaning has been an experimental matter at Amager. They tried acoustic (sonic) cleaning. They also tried vibrating (mechanical rapping) the tubes. Now for the convection and economizer sections, falling steel shot is used routinely. On shutdowns; the first, second, and third open radiation passes are manually brushed clean.

Mr. Pinto referred several times to their corporate position of not participating in the municipal waste to very high temperature steam systems. They will not sell anything that would likely have corrosive failures within a year or two. As Mr. Pinto stated, "It's not fair (to the customer) to build a system that might fail".

Volund later clarified its position with the following statement. "The highest temperature in any of the Volund plants is 490 C at Ortvikens Papperbruk, Sundsvall, Sweden. The plant which is

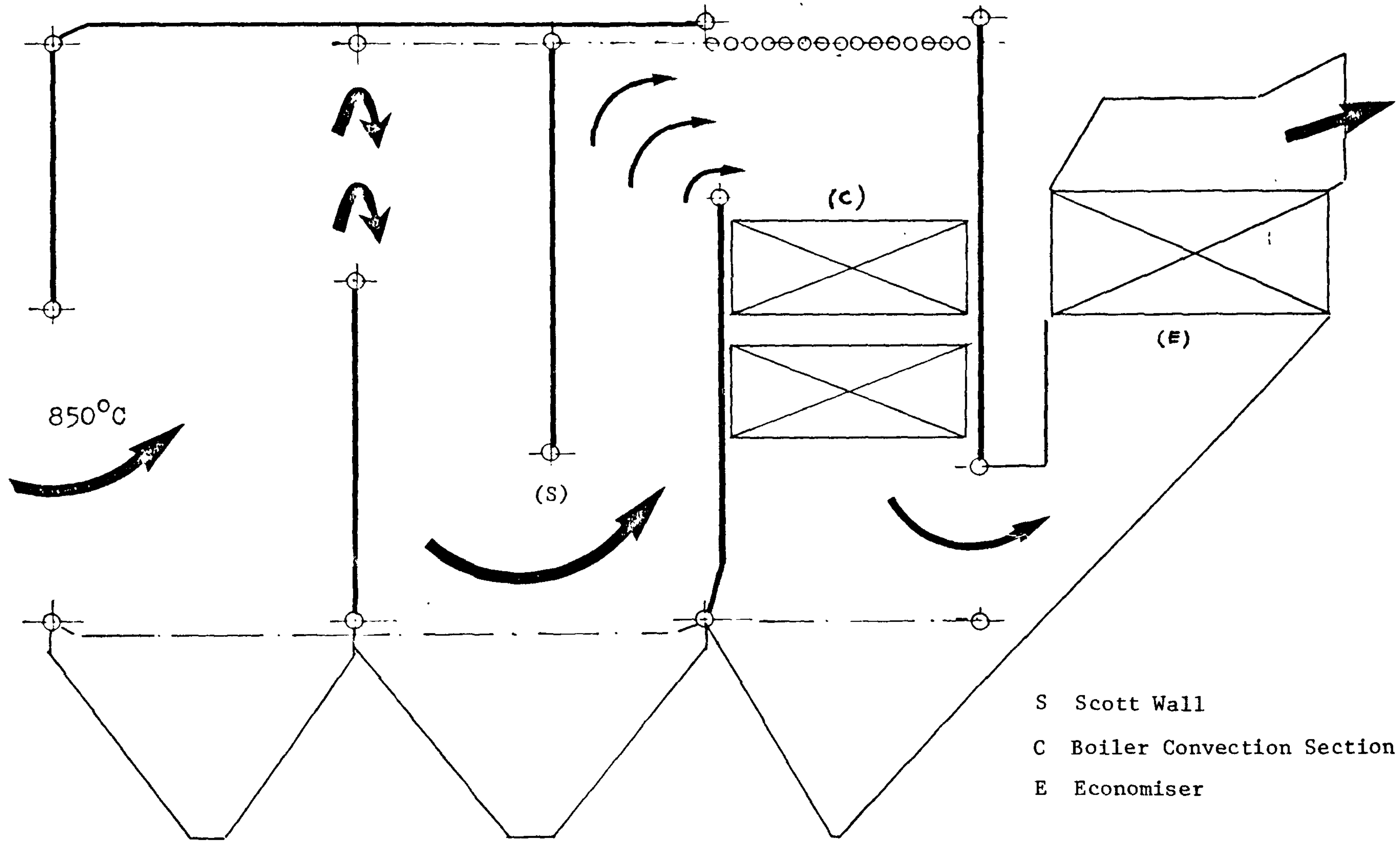

FIGURE 14-29. AMAGER BOILER DESIGN

mainly for bark incineration is equipped with an Eckrohr boiler, which produces steam at 425 C, and in a separate overheater the temperature is brought up to 490 C - 67 ato.

Sundsvall, Sweden - steam:	28.5 t/h - 67 ato - 490	C
Itabashi, Japan, - steam:	28.9 t/h - 16 ato - 203,4	C
Nishinomiya, Japan - steam:	14.6 t/h - 18 ato - 208,8	C
Kawagushi, Japan - steam:	15.8 t/h - 16 ato - 203,4	C
Kohnan, Japan - steam:	35.9 t/h - 16 ato - 203,4	C
Boras, Sweden - steam:	16.5 t/h - 10 ato - 285	C

If a customer wanted excellent burnout rates, wanted 500 C (932 F) steam, and showed high interest in Volund; then Volund might submit a bid. Volund could propose to raise the steam temperature to 300 C (572 F) by burning refuse. The steam would then be input to a topping off fossil fuel (likely oil) boiler to raise it to the 500 C (932 F) level demanded.

Convection Section

An interesting corrosion problem developed at Amager, but not West, due to the temperature of the entering feedwater. Amager's returning warm water is about 70 C (158 F). The manufacturer had warned the system owner that this would put the metal temperature at the entrance to the convection boiler section in a dangerous "dew point corrosion" temperature zone. Another cause for the dew point corrosion was the many early (first 2 years) shutdowns due to crane malfunction.

Thus, with accepted forewarning, the system was constructed. Some of the lower convection section bundles were replaced after 30,000 hours because of dew point corrosion.

Later when the complete line was overhauled after 42,000 hours, the entire convection system was replaced. There are thicker tubes on the bottom and thinner tubes on the top. Officials now hope that the unit can go for 60,000 hours without corrosion rupture.

Economizer

The economizer and its steel shot cleaning system both were supplied by Eckstrom of Stockholm, Sweden. As at West, the Amager economizers were fin tube with small spaces. The spaces and corners became so clogged with flyash and steel shot, that they will have to be replaced. Because of the clogging, the economizers at both Amager and West have set the overhaul schedule for the whole plant. Until the economizers are replaced, the unit will continue to shutdown every 1,500 to 2,200 hours. The manufacturer's original recommendation of shutdown for inspection and cleaning every 3,000 hours would have been mainly to restore efficiency. The economizer is cleaned manually with brushes.

It is likely that the electrostatic precipitator corrosion problems experienced were caused by the clogged economizer not doing its job, i.e. lowering economizer flue gas exit temperature to below 300 C (572F).

Unfortunately, shot cleaning was not in the original design. Therefore, on retrofit, the falling shot was down--concurrent to the flue gas. In future economizer designs, both the gas flow and the steel shot flow will be downward.

Boiler Water Treatment

The boiler feedwater is thoroughly treated at the adjoining power plant. Treatment includes deaerating, desalting and demineralizing.

Cofiring

Cofiring is not a significant practice at Amager. However, and for the record, in 1931 Volund did cofire Gentofte with bark and coal in a 3-1/2 tonne/day unit. In late 1977, Volund had a proposal to a Polish city that included cofiring of refuse and coal.

The reader is referred back to the Waste Input Section where there is a discussion about original inclusion of sewage sludge and waste oil. Currently there is some sewage sludge coarse ridlings put directly into the pit for mixing with refuse. No appreciable waste oil is cofired.

ENERGY UTILIZATION EQUIPMENT

Figure 14-30 shows the refuse burning plant in the foreground with the larger conventional power plant, owned by Copenhagen Gas and Electric, in the background. The refuse plant is a base load plant. The conventional plant, being the peaking plant, can adjust its operations to ensure steady energy delivery depending on season.

The refuse plant's hot water is sent to the electricity plant, but it is not used to make electricity. Rather, the hot water is combined with the electricity plant's waste heat and together they supply the Amager Island district heating network.

The Amager refuse plant sells its hot water for a lower price than does the West plant for several reasons: (1) the water temperature is lower at Amager and hence contains less energy per pound; (2) the single distribution pipe to the power plant is only a couple of hundred feet; (30 Copenhagen Gas and Electric Authority (CGEA) handles the district heating distribution, so the refuse plant has no distribution expenses, and (4) the refuse plant's energy competes with the CGEA plant's waste heat.

Roughly 1.2 Gigacalories (4.76 million Btus) can be added to water per tonne of refuse burned. At Amager, the annual average sale price to CGEA varies from 55 to 60 D.kr. per Gcal ($2.40 to 2.62/million Btus). The formula is somewhat unique. If the CGEA electric power plant is working and producing its own waste heat, then the energy value paid to the refuse plant is 60 percent of the comparable oil price for the same energy. However, if the electric power plant is not in operation, then the refuse plant receives 100 percent of the comparable oil price. All calculations are based on heating value and not on volumes of water.

Under this arrangement, the refuse plant sold 70 percent of its production during 1975-1976. The percentage has been increasing from year to year.

Belysningsvaesen or Copenhagen Gas and Electric Co. was the consultant for Amager Incineration and was in charge of the project as their experience power stations was assumed to be of value.

The plan with Amager Incineration was to sell district heating to the communities forming the partnership. The Power Station next to Amager Incineration has a surplus of waste heat in much more quantity than

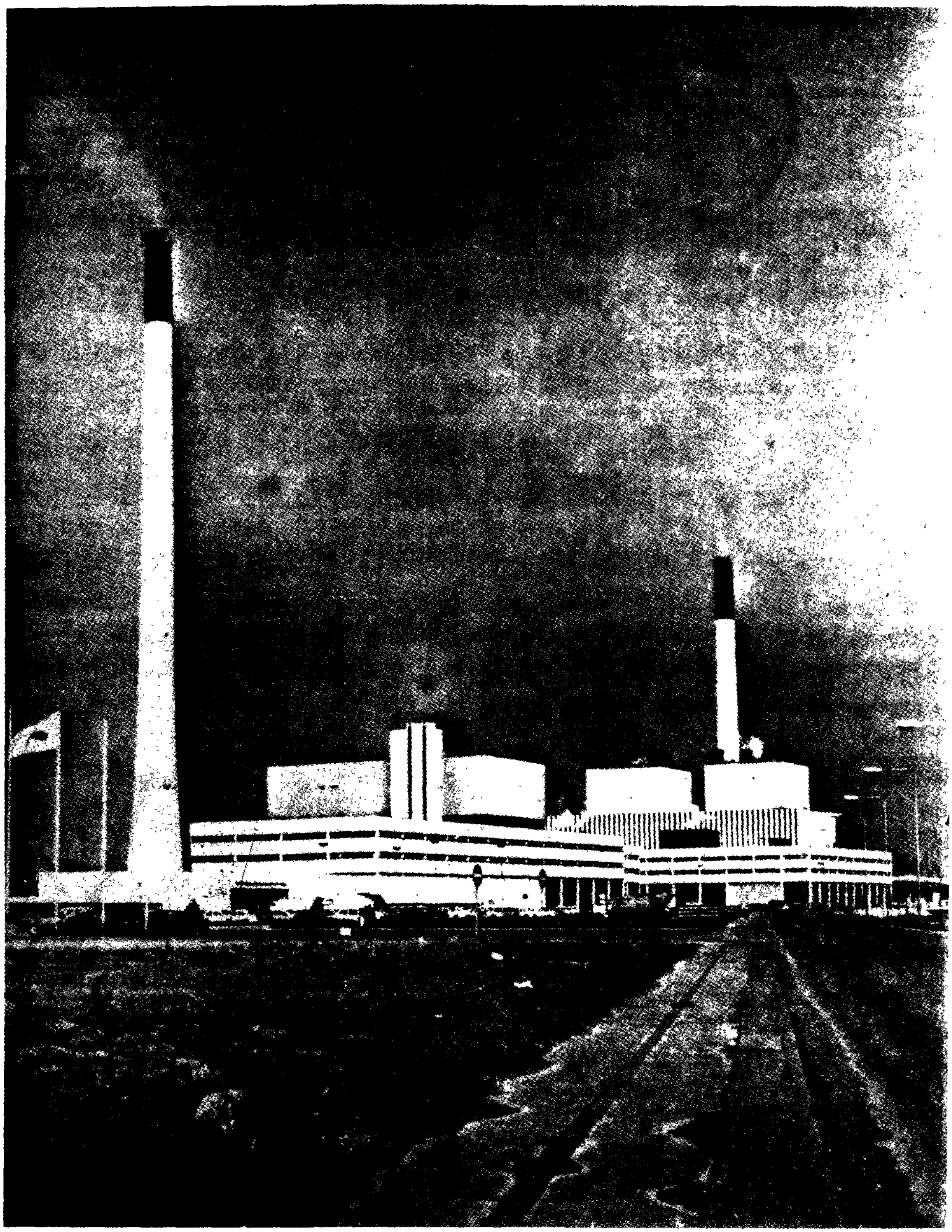

FIGURE K-49. COPENHAGEN: AMAGER'S REFUSE FIRED ENERGY PLANT IN THE FOREGROUND AND THE OIL (OR COAL?) FIRED PLANT IN THE BACKGROUND the Incineration plant. Thus to avoid competion and duplicate pipelines, an agreement took place where Amager sells the heat to the Power Station. Nevertheless by 1982 the Amager plant shall have installed Unit No. 4 and all the heat produced can be sold as a pipeline under the canal to the Copenhagen city, where a pipeline will be installed in the meantime and better prices for the sold heat will be achieved.

Heavy insulated water pipes are shown in Figure 14-31a. The pumps used to send steam to the combined district heating system are shown in Figure 14-31b.

Amager produces hot water at 115 to 120 C (239 to 248 F) at 6 kg/cm^2 (85 psi). As stated before, this is lower quality hot water than the superheated water at West. Amager sends its share of the energy to the power plant which then distributes it to the district heating system shown in Figure 14-31c. Of the total energy sold, 50 percent goes directly to household radiators. The other 50 percent transfers its energy through water-to-water heat exchangers before going to radiators..

The total energy delivered to the district heating system is shown in Figure 14-32. Note that the summer base load is usually 8,000 Gigacalories while the winter peak load is around 20,000 Gigacalories. Presumably a few industries, hospitals, etc. provide the base load in the summer.

The 1975-1976 energy sold amounted to 188,253 Gigacalories (746,988 million Btus) for a revenue off 4,877,703 D.kr.($812,950). Dividing revenue by quantity results in an average sale price of 25.91 D.kr./Gcal (1.09/million Btus).

Since the hot water is "priced" at $2.40 to 2.62 per million Btu and the "average revenue" over a year's time is only $1.09 per million Btu; it is assumed that only 44 percent of the hot water generated is sold.

Having monitored events at the Nashville (Tennessee) Thermal Transfer Corporation (NTTC) we must point out to the reader that more revenue derives from district cooling than from district heating. We ask the retorical question, "Is there a future for district cooling for European systems that will even the seasonal revenues from energy production and raise annual revenues?"

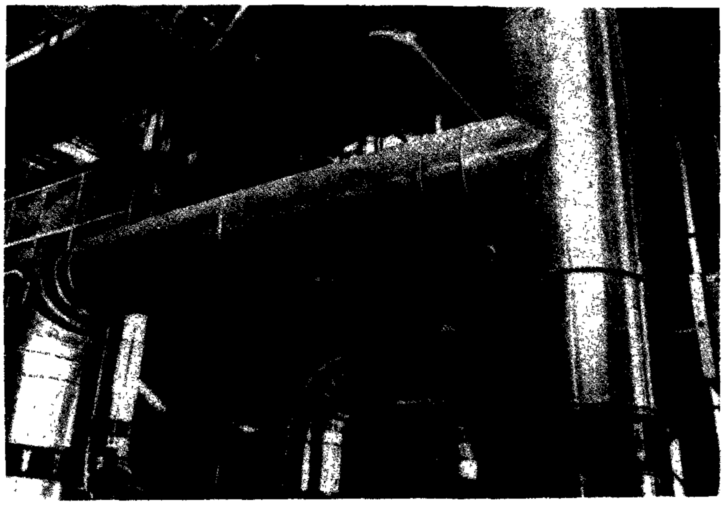

FIGURE 14-31a. INSULATED HOT WATER PIPES LEAVING BOILER AT AMAGER

FIGURE 14-31b. PUMPS TO SEND HOT WATER TO THE POWER PLANT WHICH SENDS THE HOT WATER TO THE DISTRICT HEATING NETWORK AT AMAGER

FIGURE 14-31c. MAP OF DISTRICT HEATING NETWORK OF AMAGER ISLAND

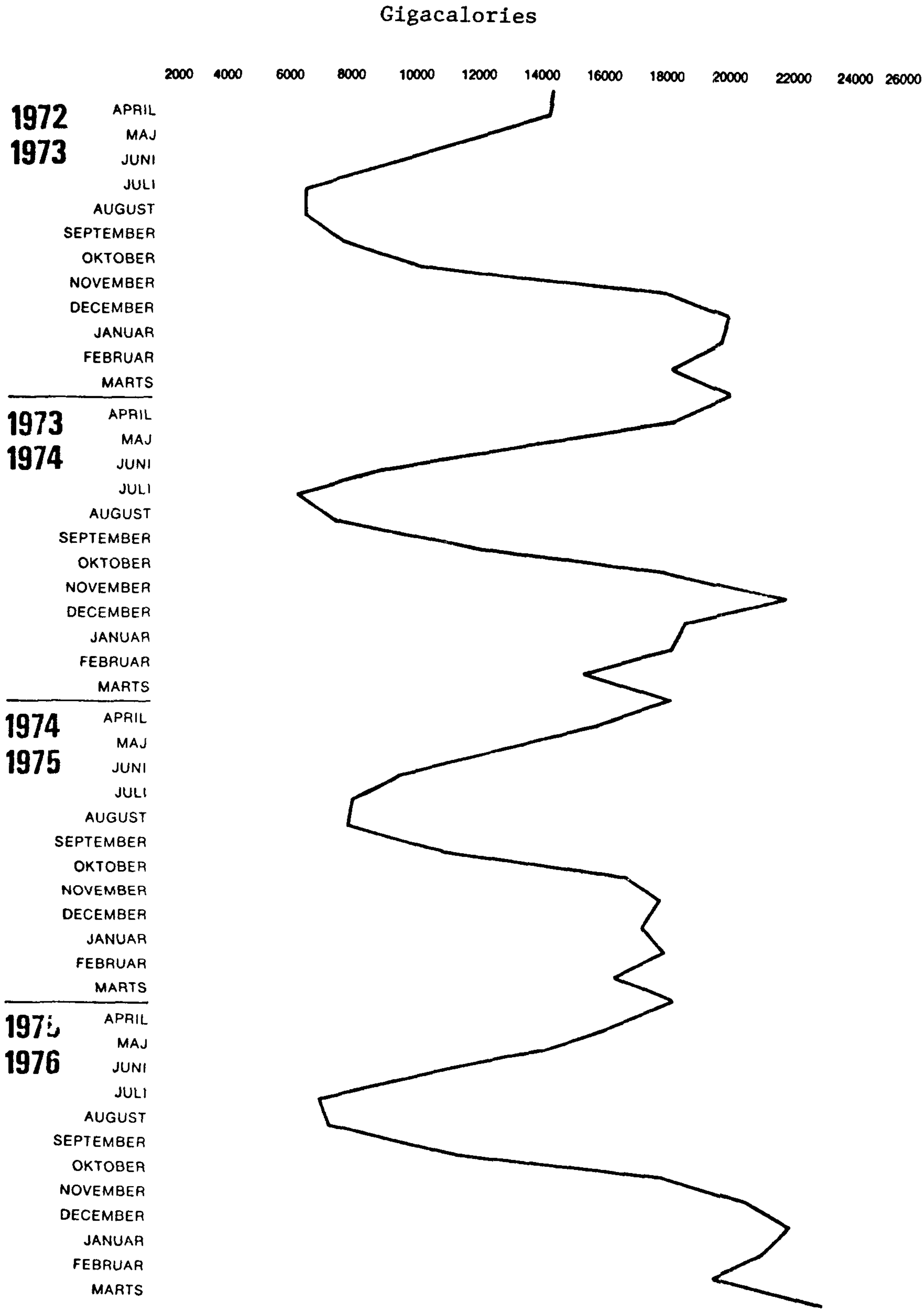

FIGURE 14-32. ENERGY DELIVERY TO THE DISTRICT HEATING NETWORK

More of Mr. Blach's Comments on Heat Exploitation

"It will always be economically profitable to exploit the heat from an incinerator plant, whenever possible.

The heat can be used for district heating, various industrial purposes, drying and burning of sewer sludge or other sludge products, and for production of electricity.

If the heat cannot be exploited, other arrangements must be made to cool the 900-1000 C(1652 0 1832 F), hot flue gas to about maximum 350 C (662 F), before it is led into the precipitator and the chimney.

Such a cooling of the flue gas can be done by adding air, water spray, a combination of water spray and air, or by letting the flue gas through a waste heat boiler and then cool the water or steam.

Initial expenditures of plant as well as operational costs for the cooling plant with air, water spray, or a combination are just as high as the costs of an actual plant for heat exploitation with a possible supplementary air cooler. The sale of heat, therefore, is an actual working income, which contributes essentially to the operation of the plant, even with regard to the extra costs for repair caused by wear and corrosion in the convection part of the boiler part.

Least profitable is the production of electricity as the costs of high pressure boilers and turbines are too high and the efficiency too low compared with the low price at which the big power stations can produce the electricity. There is a great need for drying and burning sludge, and the use of waste heat for the purpose can be expected to be common in the future. Sale of heat for district heating or industrial purposes has, therefore, up to now been the solution which technically and economically has shown the best results."

POLLUTION CONTROL EQUIPMENT

Air Pollution

Both at Amager and West, Rothemuhle two field electrostatic precipitators (ESP) are the sole means of air pollution control now in efffect. Plant officials were initially hesitant about this and had thought of the need to add a mechanical cyclone collector after the ESP. They wanted to make sure that the larger paper particles would for certain be captured. Therefore, they mandated that room should be available for adding the cyclones later if necessary. The space is outlined with dash lines in the previous Figure 14-1. As discussed later, there has been no need to add any cyclones.

The ESP inlet gas flow is 107,000 Nm^3/hour. The flue gas temperature is designed to be around 300 C (662 F) with a 350 C (662 F) maximum. Because of the clogging economizer section of the boiler, there have been many excursions well about 350 C (572 F). As a result, there has been some corrosion at the top and front end of the ESP. Volund estimates the inlet loading to be 7.5 g/Nm^3.

Each of the two fields is 8.5 m (28 ft) high, and 7.0 m (23 ft) deep. Flow-model studies were not conducted before installation. The average flow velocity is 0.86 m/sec (0.26ft/sec). The maximum is 1 m/sec (3.3 ft/sec). Each ESP field has two rectifiers. Volund would permit a one-field ESP only on a small system where the regulations are not as stringent.

Again it is helpful to quote from the Interersentskab brochure:

> "In the electrostatic filter the speed of the smoke is reduced to approximately 1 m/s, after which the smoke passes between vertically suspended, electrically earth connected profiled steel sheets. The mutual distance between the sheets is about 25 cm (10 inches). Tightly stretched between the sheets are a great number of steel wires, equipped with spikes. The steel wires are insulated when hung and are connected with an 80,000 volt direct current generator. When the smoke slowly passes this system of negatively charged steel wires, the dust particles carried along will be electrically charged and will

therefore be pulled over onto the earth-connected (grounded) sheets. Thus, a continuous layer of dust will gradually be formed on the sheets and can be shaken off by hard blows on the sheets. This causes the lumps of dust to drop into accumulation funnels. The flyash at Amager falls into a water bath and is transported to a rubber belt conveyor by a screw conveyor.

The total efficiency of the electrostatic filter is more than 98 percent. During 1972, approximately 5,000 tons of fly ash was separated through Amagerforbraending's filters."

Even though the ESP is housed inside the normally warm furnace/boiler room, the ESP hoppers are equipped with electric heaters. When the room temperature falls to 10 C (50 F), the heaters are turned on to prevent possible dew-point corrosion in the ESP.

Fly ash is removed from the bottom of the ESP hoppers pneumatically. The pneumatic tube dumps onto a conveyor belt for transport to the ash bunker to be humidified.

During the plant tour, a "gray smoke indicator" registered values between 6.5 and 8.0 on the Ringleman scale. The 0^2 meter was not working.

Upon startup, the unit exceeded the 150 mg/Nm^3 limit for particulates. The primary reason was that a standard ESP (without special entrance vanes) was used to clean a very highly loaded flue gas. The Amager estimate of 7.5 g/Nm^3 compares with more typical inlet loadings of around 5 g/Nm^3. This 2.5 g/Nm^3 difference is attributed mostly to use of the rotary kiln compared to a grate only system.

Because of noncompliance, Rothemuhle complied with its guarantee. They then did conduct flow model tests. Turning and guide vanes were added. The tests proved so successful that they again concluded that cyclones would not have to be added.

The new Danish air pollution regulations specify limits for particulates, HCl, and SO_2 (corrected to 11 percent O_2 and 7 percent CO_2). Amager tests show that the unit is now well within the limits.

	Danish Law	Amager Plant
Particulates (mg/Nm^3)	150	60- 90
HCl (mg/Nm^3)	1,500	700-900
SO_2 and SO_3 (mg/Nm^3)	1,500	200-300

Because the HCl and SO_2 gases are in compliance, no scrubber has been needed. A new feature of the law is that particulate tests are to be made every month. The sampling point is 50 m up the 150 m chimney. The respected Danish Boiler Testing Company is employed to perform the tests.

One emissions analysis reported is as follows:

Nitrogen (N_2)	66.40%
Oxygen (O_2)	12.40%
Carbon Dioxide (CO_2)	12.40%
Water (H_2O)	8.64%
Hydrogen Chloride (HCl)	0.06%
Sulfur Dioxide (SO_2)	0.01%
Unidentified and Measuring Errors	0.09%
TOTAL	100.00%

(Nitrogen is normally 78 or 79 percent on a dry gas basis (no H_2O). But even dropping the H_2O out, the N_2 is still not near 78 percent. This analysis appears in the attractive brochure Amager-forbraending Interessentskab. The Volund system does not produce much NO_x relatively due to the lower combustion temperatures.

Officials repeated a statement heard elsewhere in Europe and America that, "for each 1 percent above 96 percent efficiency, the ESP purchase price doubles". This, of course, is far from accurate. However, it makes the clear point that going from clean air emissions to very clean air emissions is very expensive.

Water Pollution

Amager discharges a small amount of waste water directly into the canal.

ASH HANDLING AND DISPOSAL

Unfortunately, the new handling system at Amager caused considerable problems. West designed differently and operates much better. Basically, Amager uses a sluice, pusher and conveyors (see Figure 14-33) while West uses a skip hoist (see Figure 14-34).

Because of the high temperature on clinkers at furnace outlet (rotary kiln outlet) an ash pusher alone cannot do the perfect job as the necessary air tighteners would be lost when it is not possible to maintain an ash column on the chute.

If the ashes can be held in the chute and thus create air-tighteners between the atmosphere and the vacuum inside the furnace as it is the case in small furnaces without rotary kiln, the ash pusher alone is the ideal solution on servicew and economy.

But the accumulation of ashes of 800°C will result in a condense mass of clinker impossible to discharge.

To avoid the problem a sluice is included in the system maintaining airtightness and in the same chute a water spray cooling is included.

Originally the Amager rubber conveyors (Figure 14-35a) let too much water and fine ash out and into the tank bottom. The material would settle, build up, and then interfere with the conveying. There was excessive wear on rollers and nylon bearings. Downtime for repair and fines removal was excessive.

To partially solve the problem, stainless steel apron conveyors were replaced by vibrating conveyors. They have also installed air pipes in the bottom of the fines tank to keep the siftings in solution so they can be removed.

Another major difference is that Amager uses about 3 tonnes of water per tonne of ash while West uses only 1 tonne of water per tonnne of ash.

Ash disposal at Amager is entirely different from the treatment at West. The ash is simply trucked (Figure 14-35b) to reclaim further portions of Amager Island. It is very profitable in that 1 m^2 (1 yd^2) of land reclaimed from the sea is worth 200 to 300 D.kr. ($35 to 52). About 3 m^3 (4 yd^3) volume of ash is used to reclaim a 1 m^2 (1 yd^2) area.

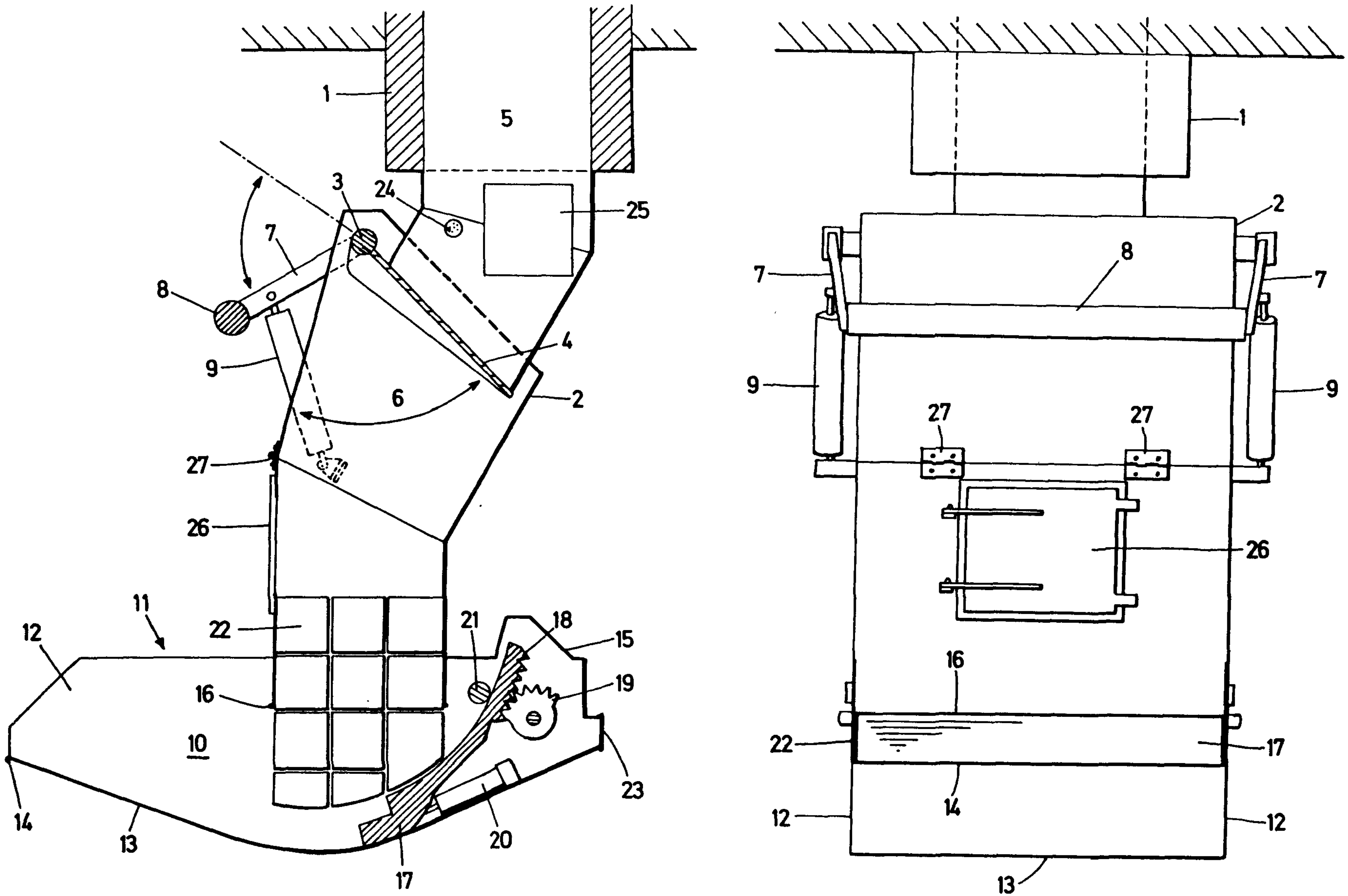

FIGURE 14-33. PATENT FOR VOLUND'S ASH SLUICE AND PUSHER.

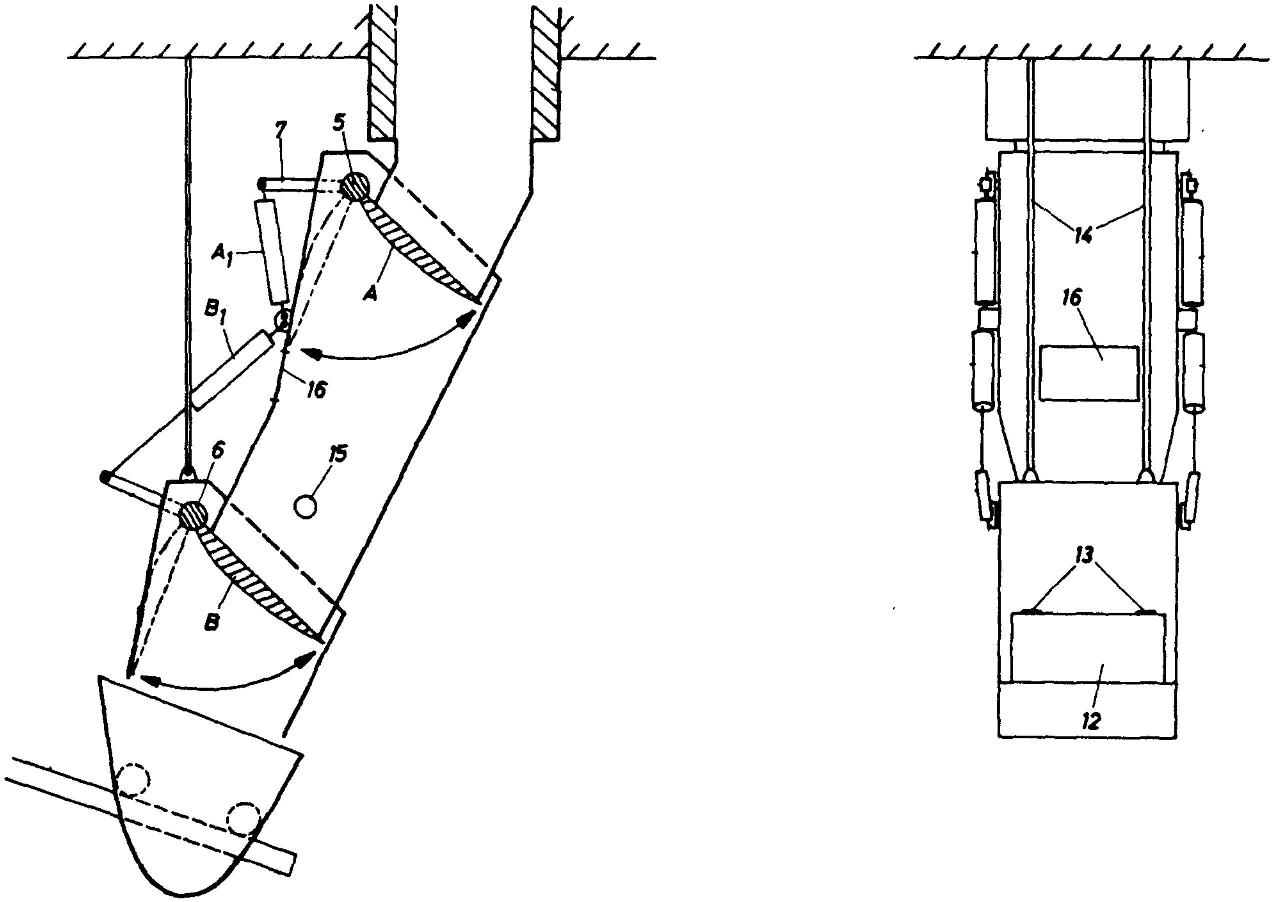

FIGURE 14-34. ASH CHUTE AND SKIP HOIST AT COPENHAGEN: WEST

FIGURE 14-35a. RUBBER ASH CONVEYOR AT COPENHAGEN: AMAGER

FIGURE 14-35b. FERROUS SEPARATION FROM ASH AT COPENHAGEN: AMAGER

CHIMNEY

The chimney was constructed by a local contractor, Ramboll Hannemann, using a Polish patented system for continuously pouring concrete. The stack has a 2.8 m (9.2 ft) diameter. Most of the stack is lined with 280 mm (11 inch) thick plain carbon steel. The flue gas velocity is 27 m (89 ft/sec). At the top 10 m (33 ft), there is a corten steel that is used to prevent corrosion. The stack height is 150 m (500 ft).

PERSONNEL AND MANAGEMENT

Personnel

Amager's personnel structure is based on five shifts: early mornings, days, nights, weekends, and replacements. Each shift has four key men--the supervisor, boiler tender, furnace tender, and crane operator--for a total of 20 operating men.

Another 23 men are utilized in maintenance, repairs, and cleaning. Two men are used at the scale house and two are used on the tipping floor.

The administration personnel number six people: the director, operating manager, office manager, two office employees, and a canteen lady.

Realizing that the plant runs 24 hours per day, 365 days per year, many of the above personnel are used as vacation, holiday, and sick replacements. Considering this, the total plant staff numbers 53 employees.

Management

The Amager operations are managed by representatives from the five communes listed in Figure 14-36. Note that 18 people attend the annual general meeting (community stockholders meeting).

More frequent meetings are held with the management committee of six representatives: a chairman, and the borgomiester from each commune.

Finally, the day-to-day administrative director is the focal point for the communities with the plant personnel.

1975-76

COMMUNES

Dragør kommune
Frederiksberg kommune
Hvidovre kommune
Københavns kommune
Tårnby kommune

REPRESENTATIVES TO THE ANNUAL COMMUNITY SHAREHOLDERS MEETING

Borgmester Alb. Svendsen
Viceborgmester Chr. Lauritz-Jensen
Landsformand Arne Ginge
Borgmester Svend Aagesen
Kommunalbestyrelsesmedlem Jens Kristensen
Kommunalbestyrelsesmedlem Alf Christensen
Borgerrepræsentant Gunnar Ulbæk
Borgmester Lilly Helveg Petersen
Borgmester A. Wassard
Forretningsfører Andreas E. Hansen
Overborgmester Egon Weidekamp
Overlærer Kit Falbe Hansen
Skoleinspektør Niels Jørn Hougård
Typograf Kurt Kristensen
Havnemester Elhardt Madsen
Borgmester Tork. Feldvoss
Generalauditør Jens Harpøth
Journalist Marcelino Jensen

MANAGEMENT COMMITTEE

Borgerrepræsentant Gunnar Ulbæk (formand)
Borgmester Lilly Helveg Petersen
Viceborgmester Chr. Lauritz-Jensen
Borgmester Tork. Feldvoss
Borgmester Svend Aagesen
Borgmester Alb. Svendsen

ADMINISTRATIVE DIRECTOR

Willy Brauer (administrerende direktør)

FIGURE 14-36. MANAGEMENT STRUCTURE OF COPENHAGEN: AMAGER

ECONOMICS

Capital Cost (Assets and Liabilities)

The 1975-1976 annual report presents an accounting schedule of assets and a schedule of liabilities. These are shown in Tables 14-3.The refuse-fired hot water generating plant itself cost 117,600,000 D.kr. ($16,650,000) during the 1970-1972 construction period. The original capital costs were as follows:

Ground Work and Construction	63.0 million Dkr
Machinery	45.0 million Dkr
Other Costs	9.6 million Dkr
TOTAL	117.6 million Dkr

Since then, another 40 million D.kr. has been spent on capital improvements. Both assets and liabillities, by definition, equal 181,452,000 D.kr.

Annual Costs (Expenses and Revenues)

Annual costs and revenues are distributed as shown in Table 14-5. On the revenue side, note that the tipping fees ($6.06/t) and the general head tax ($11.33/t) provide most of the revenue totaling $17.39 per ton. Charging a tipping fee of only $6.06/ton encourages suburbs, private haulers and industries to contribute waste. If they had to support the entire $17.39 per ton, many who have freedom of choice regarding disposal, might apt for landfilling at a distant site. Having the foreing waste and its tipping fee will help carry some of the fixed expenses. The revenue from district heating, originally planned to be 2,200,000 D.kr. in this year, actually turned out to be more than double that at 4,878,000 D.kr. By definition of a "not-for-profit organization", the expenses must equal revenues. In this case, they are both equal to 36,305,000 D.Kr. ($6,272,460).

Table 14-7 presents the annual costs and revenues per tonne for almost 5 fiscal years. Note that increased revenues from the sale of heat

TABLE 14-3. ASSETS (MARCH 31, 1976) AT COPENHAGEN:AMAGER

Current Assets (Cash, Stocks, Supplies)			12,882,000 Dkr
Money on Loan to Others			2,431,000
Transfer Station			8,980,000
Landfill			1,625,000
Refuse Burning Hot Water Generator*			155,534,000
Under Surplus, 1972-1973		4,339,000	
Over Surplus, 1973-1974	1,757,000		
Over Surplus, 1974-1975	489,000		
Over Surplus, 1975-1976	2,093,000	4,339,000	
TOTAL ASSETS			181,452,000 Dkr

* Includes 7 years of improvements.

TABLE 14.4. LIABILITIES (MARCH 31, 1976) AT COPENHAGEN:AMAGER

Loan on Refuse Fired Hot Water Generator	101,920,000 D.kr.
Loan on Landfill	108,000
Short Term Creditors	2,538,000
Accrual Account for Test and Development with Waste Treatment	60,000
Accrual Account for Finalization of Building Surroundings and Machinery Works	35,000
Accrual Account for Renewal of Ash Transportation Plant (?)	1,566,000
Accrual Account for Interest and Capital Return	321,927,000
Equity in the Refuse Burning Plant	39,718,000
Equity in the Transfer Station	580,000
TOTAL LIABILITIES	181,452,000 D.kr.

TABLE 14-5. ANNUAL COSTS DURING 1975-1976 AT COPENHAGEN:AMAGER

Operational Salaries	5,028,000 Dkr
Other Operation Expenses	2,196,000
Ash Disposal Expenses	769,000
Transfer Station Expenses	4,008,000
Landfill Operation Expenses	853,000
Administrative Expenses, Meetings	197,000
Administrative Salaries	514,000
Other Administrative Expenses	224,000
Plant Maintenance	2,415,000
Government Taxes and Other Fees	1,018,000
Interest on Loan	7,425,000
Depreciation on Plant	8,000,000
TOTAL EXPENSES	32,647,000 Dkr
Account Set Aside to Build an Ash Transportation Plant	1,566,000*
Surplus Returned to Asset Account	2,093,000
GRAND TOTAL	36,305,000

* Amount set aside for changing (1) existing ash discharge plant with new (1977) ash transport plant (2) existing rubber belts with vibrating conveyors (3) magnetic separation and (4) ash treatment prior to selling.

TABLE 14-6. REVENUES DURING 1975-1976 AT COPENHAGEN:AMAGER

Communities' Tipping Fee at 40 Dkr/tonne* ($6.06/ton)	7,872,000 Dkr
Government (?) Tipping Fee at 40 Dkr/tonne*	169,000
Private Haulers' Tipping Fee at 40 Dkr/tonne*	2,423,000
Head Tax at 30 Dkr/year* ($4.55/year)	16,441,000
Revenue From Energy Sale to District Heating Network	4,878,000
Transfer Station Tipping Fee (?)	2,743,000
Landfill Tipping Fee	515,000
Interest Earned on Current Assets	1,019,000
Rent of Excess Office and Filing Space	246,000
TOTAL REVENUES	36,306,000 Dkr

*Net Disposal Fee = tipping fees + head tax

$$= \frac{\$6.06}{\text{ton}} + \frac{\$4.55}{\text{person year}} \left(\frac{1 \text{ year}}{365 \text{ days}}\right)\left(\frac{1 \text{ day person}}{2.2 \text{ pounds}}\right)\left(\frac{2000 \text{ lbs}}{1 \text{ ton}}\right)$$

$$= \$6.06/T + \$11.33/T$$

$$= \$17.39 \text{ per ton}$$

Assumes 6.00 D.Kr. per U.S. $ in 1975-76

	1972-1973	1973-1974	1974-1975	1975-1976	1976 (9 mo)
Tonnes Burned	220,000	226,000	224,000	255,000	190,000
Wages	12.14	14.04	18.34	19.72	20.99
Operation Expenses	5.84	5.97	9.42	8.61	9.77
Clinker Disposal	2.17	2.26	2.72	3.01	3.38
Administration	2.72	2.70	3.48	3.67	4.25
Maintenance Expenses	3.74	5.92	12.35	9.47	11.25
Taxes and Insurance	3.87	4.06	4.17	3.99	4.43
Operations and Maintenance	30.48	34.95	50.48	48.47	54.07
Interest Expense on Loans	39.45	38.01	35.44	29.12	36.00
Depreciation	36.36	32.73	39.29	31.37	31.58
Total Cost	106.29	105.69	125.21	108.96	121.65
Revenue From Energy Sale	7.00	9.22	19.10*	19.13	18.23
Net Operating Income	99.29	96.47	106.11	89.83	103.42
Revenue From Interest	--	0.56	4.48	3.99	6.59
Revenue From Rent and Transfer Services	1.10	0.94	1.09	0.96	0.96
Net Cost	98.19	94.97	100.54	84.88	95.87

* Dramatic year-to-year rise in income from sale of heat due to the oil crisis.

have offset increases in operating costs so that the net cost to the taxpayer has remained relatively steady for 5 years.

Profitableness at Exploitation of Heat

For the final time, Mr. Blach's comments are entered into the American record.

He presents the analytical logic one would expect supporting "economy of scale theory". We, however, have learned that in actual practice there is little economy of scale. Designers and customers of large plants tend to mitigate the potential economies by extra "bells and whistles" which would not be considered in the small plant.

This presents the economics of a 3 x 12 t/hr plant versus a 3 x 3 t/hr plant. The analysis uses three different Kcal/kg estimates and two utilization rates.

> "As mentioned before, the cost of the installation of a boilèr for the recovery of the waste heat can be expected to be of the same magnitude as the cost of other forms of installation for the cooling of the flue gas. In the same way, the operational and maintenance costs can be calculated to be of the same magnitude provided the boiler construction is executed correctly and appropriately, taking into consideration the special corrosive, wearing, and clogging properties of the flue gas.
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> As previously mentioned, the income from the waste heat sales will be a real operational income which can cover a larger or smaller part of the operational costs, depending on how large an amount of the produced heat can be sold and at which price. The following enclosed two tables (Tables 14-8 and 14-9) show examples of operational costs (exclusive of interest and depreciation) and incomes resulting from heat sales from a large plant with three units of 12 t/h and a smaller plant with three units of 3 t/h. Figures are calculated for net calorific values of 1,500, 2,000, and 2,500 Kcal/kg. Plant utilization for the smaller plant is 50 percent and 75 percent, respectively, and for the larger plant 65 percent and 80

TABLE 14-8. OPERATIONAL COSTS (EXCLUSIVE OF INTEREST AND DEPRECIATION) AND INCOME BY HEAT SALE FROM A PLANT WITH THREE FURNACES OF 12 t/h FOR VARIABLE NET CALORIFIC VALUES OF REFUSE AND DEGREE OF INCINERATION CAPACITY

Plant capacity: 3 x 12 t/h Theoric nominal max. capacity: 3 x 12 x 24 x 365 = 315.360 t/year	Net Calorific Value, Hg — 1,500 Kcal/kg		2,000 Kcal/kg		2,500 Kcal/kg	
	Degree of Utilization					
	65%	80%	65%	80%	65%	80%
1. Effective incinerator capacity (t/year)	205,000	252,300	205,000	252,300	205,000	252,300
2. Produced heat at 65% effectivity (Kcalx10^6/year)	199,900	246,000	266,500	328,000	333,150	410,000
3. Presumably sold heat (75%)	150,000	184,500	199,900	246,000	249,900	307,500
4. Income by heat sale at presumably 20 Dan.kr/ 10^{6}Kcal (Dan.kr./year)	2 998,200	3,689,900	3,997,500	4,919,900	4,996,900	6,149,300
5. Do. (4:1) (Dan.kr/t)	14.70	14.70	19.50	19.50	24.40	24.40
6. Calculated operational costs (excl. interest and depreciation) (Dan.kr/year	6,400,000	7,300,000	6,400,000	7,300,000	6,400,000	7,300,000
7. Do. (6:1) (Dan.kr/year)	31.50	29.00	31.50	29.00	31.50	29.00
8. Operational costs-heat sale (6-4) (Dan.kr/year)	3,401,880	3,610,112	2,402,500	2,380,150	1,403,120	1,150,200
9. Do. (7-5) (Dan.kr/year)	16.60	14.30	11.80	9.50	7.00	4.60

TABLE 14-9. OPERATIONAL COSTS (EXCLUSIVE OF INTEREST AND DEPRECIATION) AND INCOME BY HEAT SALE FROM A PLANT WITH TWO FURNACES OF 3 t/h FOR VARIABLE NET CALORIFIC VALUES OF REFUSE AND DEGREE OF INCINERATION CAPACITY

Plant Capacity: 2 x 3 t/h	Net Calorific Value, Hg					
Theoric nominal max. capacity:	1,500 Kcal/kg		2,000 Kcal/kg		2,500 Kcal/kg	
	Degree of Utilization					
2 x 3 x 24 x 365 = 52.560 t/year	50%	75%	50%	75%	50%	75%
1. Effective incinerator capacity (t/year)	26,280	39,420	26,280	39,420	26,280	39,420
2. Produced heat at 65% effectivity (Kcalx10^6/year)	25,700	39,500	34,200	51,300	42,800	64,100
3. Presumably sold heat (75%)	19,300	28,900	25,700	39,500	32,100	49,100
4. Income by heat sale at presumably 20 Dan.kr/ 10^6Kcal (Dan.kr./year)	384,400	576,600	512,500	768,700	640,600	960,900
5. Do. (4:1) (Dan.kr/t)	14.70	14.70	19.50	19.50	24.40	24.40
6. Calculated operational costs (excl. interest and depreciation) (Dan.kr/year)	1,100,000	1,570,000	1,100,000	1,570,000	1,100,000	1,570,000
7. Do. (6:1) (Dan.kr/year)	42.00	40.00	42.00	40.00	42.00	40.00
8. Operational costs-heat sale (6-4) (Dan.kr/year)	752,000	993,500	587,000	801,300	459,500	609,200
9. Do. (7-5) (Dan.kr/year)	27.30	25.30	22.50	20.50	17.60	14.60

percent, respectively, of the nominal capacity. As a total sale of the produced heat all the year round cannot normally be expected, there has only been calculated the incomes driving from sales of 75 percent of the produced heat.

The obtainable selling price for the heat--here rated to Dkr. 20, -per million Kcal--will be determined by the fact that it should be able to compete with the production price for a normal oil-fired plant, i.e., among other things, it will be dependent on the price of oil. When in competition with heat from power stations, the selling price is lower (Dkr. 12,--15,--per million Kcal).*

As shown on the tables, the incineration capacity (Line 1) and operational costs (Line 6) are equally rated for the different calorific values. This, of course, is an approximation, but nevertheless close to the real figures as far as the operational costs are concerned, which will increase only little with the increase of the calorific value, whereas the incineration capacity may vary with the calorific value, depending on the refuse composition, so that the capacity can normally be expected to increase for lower calorific powers. This means that the values for the operational costs per ton refuse incinerated can be expected to be proportionately lower for the refuse with the lower calorific value than for the refuse with the high calorific value.

As regards the small plant, there has been calculated with two-shift operation at 50 percent exploitation and three-shift operation at 75 percent exploitation, and the plant closed on Saturdays and Sundays. For the larger plant, calculations are based on continuous operation all days of the year.

It can be seen that the operational costs per burnt ton of refuse are much cheaper for the large plant than for the smaller one. The operational costs for the small plant executed as grate furnace and with mechanical gas cleaning, and for the large plant executed as grate/rotary kiln furnace with electrostatic precipitator, will be almost equal per ton of plant capacity. With uniformly rated interest and depreciation conditions, the

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* The selling price of 12-50 D.Kr./million Kcal is an old price used in 1975-1976. Prices today (1978) are 30-60 D.Kr./Gcal ($1.35-$2.70 per million Btus).

large plant will consequently also have the lower total operational costs per treated ton of refuse.

Accordingly, with the large plant, a more effective and secure refuse treatment, a better gas cleaning, as well as a cheaper treatment price are achieved."

FINANCE

The financial arrangements were straightforward. The 5 municipalities put in money based on population. The remainder was borrowed at local banks. The payoff period is variable as well as the interest rate that has averaged about 8 percent.

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