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Solid Waste

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European Refuse Fired Energy Systems

Evaluation of Design Practices

Volume 9

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and State Solid Waste Management Agencies

EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

<u>Gothenburg-Savanas Plant</u>
<u>Sweden</u>

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Volume 9

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

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An environmental protection publication (SW-176c.9) in the solid waste management series.

TRIP REPORT

to

GOTHENBURG-SAVENAS PLANT, SWEDEN

on the contract

EVALUATION OF EUROPEAN REFUSE-FIRED
STEAM GENERATOR DESIGN PRACTICES

to

U.S. ENVIRONMENTAL PROTECTION AGENCY

September 22-23, 1977

EPA Contract No. 68-01-4376
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February, 1978

by

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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:

VOLUME I

VOLUME II

VOLUME III

VOLUME IV

LIST OF PERSONS CONTACTED

Bengt Rundqwist	Director, Gothenburg (Savenas) Plant
Gian·Rudlinger	Chief Operating Engineer, Gothenburg (Savenas) Plant
Beat C. Ochse	Project Engineer, Von Roll, Ltd., Zurich
Kurt Spillman	Project Engineer, Von Voll, Ltd., Zurich

The authors are glad to acknowledge the very kind and competent assistance of these men in providing the information presented in this report.

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SUMMARY

The 900 tonnes/day (990 tons/day) Savenas plant at Gothenburg (Goteborg), Sweden is owned and operated by the Goteborgsregionens Avfallsaktiebolag-GRAAB (Gothenburg Regional Refuse Management Company). The heat recovered is used in district heating. There is no electricity generation. Maximum burning capacity of each of three furnaces was originally rated as 15 tonnes/hr or a total of 1,080 tonnes/day (1,188 tons/day). However, the Gothenburg refuse has turned out to have an unusually high heat value and therefore the normal capacity is now about 14th in the year 1975 corosions in the first pass of the boiler gave in all three units operating stops and therefore the utilisation is shorter. Modifications of furnace configuration and of operation have been effective in bringing these problems under control.
transfer stations and 30 specially built, large transfer vehicles.

The refuse is collected over a broad area through the use of five transfer stations and 30 specially built, large transfer vehicles.

GOTHENBURG STATISTICAL SUMMARY

Community Description:	
Area (square kilometers)	1,000
Population (number of people)	670,000
Key terrain feature	Hilly, coastal
Solid Waste Practices:	
Total waste generated (tonnes/year)	254,000 (1976)
Waste generation rate (kg/person/year)	380 kg
Lower heating value of waste (Kcal/kg)	2600 ÷ 2700
Collection period (days/week)	--
Cost of collection (local currency/tonne)	Not in GRAAB responsibility
Use of transfer and/or pretreatment (yes or no)	Yes
Distance from generation centroid to:	
Local landfill (kilometers)	8
Refuse-fired steam generator (kilometers)	6
Waste type input to system	Res., com., ind.
Cofiring of sewage sludge (yes or no)	Contemplated
Development of the System:	
Date operation began (year)	March 1, 1972
Plant Architecture:	
Material of exterior construction	Anodized aluminum
Stack height (meters)	120
Refuse-Fired Steam Generator Equipment:	
Mass burning (yes or no)	Yes
Waste conditions into feed chute:	
Moisture (percent)	about 23
Lower heating value (Kcal/kg)	2,600 - 2700

Volume burned:	
Capacity per furnace (tonnes/day) (max)	360
Number of furnaces constructed	3
Capacity per system (tonnes/day) (max.)	1,080
Actual per furnace (tonnes/day)	300-340
Number of furnaces normally operating	3
Actual per system (tonnes/day)	900 ÷ 1020
Use auxiliary reduction equipment (yes or no)	Bulky waste shears
Pit capacity level full:	
(tonnes)	2,500
(m^3)	6,000 (12,000 max)
Crane capacity (2):	
(tonnes)	11,4
(m^3) GRAB Capacity	6
Drive method for feeding grate	Hydraulic cylinders
Burning grate:	
Manufacturer	Von Roll
Type	Reciprocating/transversal
Number of Grates	3
Length overall (m)	5.425
Width overall (m)	3.40
Primary air-max (Nm^3/hr)	60,000
Secondary air-overfire air-max (Nm^3/hr)	33,000
Furnace volume (m^3)	Approx. 320 320
Boiler wall tube diameter (cm)	7.6
Furnace heating surface (m^2) proj. surface	160 m^2
Auxiliary fuel capability (yes or no)	Yes
Use of superheater (yes or no)	Yes
Boiler:	
Manufacturer	Generator AB, Gothenburg

Type		Eckrohr
Number of boiler passes		3
Steam production per boiler (kg/hr)	(max)	52,500
Total plant steam production (kg/hr)	(max)	157,500
Steam temperature (^{o}C)		214
Steam pressure (bar)		20-22
Use of economizer (yes or no)		No
Use of air preheater (yes or no)		Yes
Use of flue gas reheater (yes or no)		No
Cofire (fuel or waste) input	startup and emergency burn	Oil
Use of electricity generator (yes or no)		No

Energy Utilization:

Medium of energy transfer		Hot water
Temperature of medium (^{o}C)	(max)	180
Population receiving energy (number)		10,000 flats/and one hospital
Pressure of medium (bar)		14,5 bar
Energy return medium		Condensate from heat exchanger

Pollution Control:

Air:

Furnace exit conditions:

Gas flow rate (Nm^3/hr)	100,000
Furnace exit loading (mg/Nm^3)	Less than 150

OVERALL SYSTEM SCHEMATIC

Figure 11-1 shows a top-view sketch of the Savenas plant which is located about 6 km (3.7 mi) from downtown Gothenburg. The site is amply sized to accommodate the large transfer trucks that are an important feature of the system.

Figure 11-2 shows a view of the plant looking toward the west. The unusual multicolored wall is anodized aluminum. The tipping hall is the dark mass on the right. The elevated entrance ramp crosses the width of the main building from left to right. The chimney is 120 m (394 ft) tall. The main building is 36.1 m (118.4 ft) high. The site is 18.6 m (61 ft) above sea level.

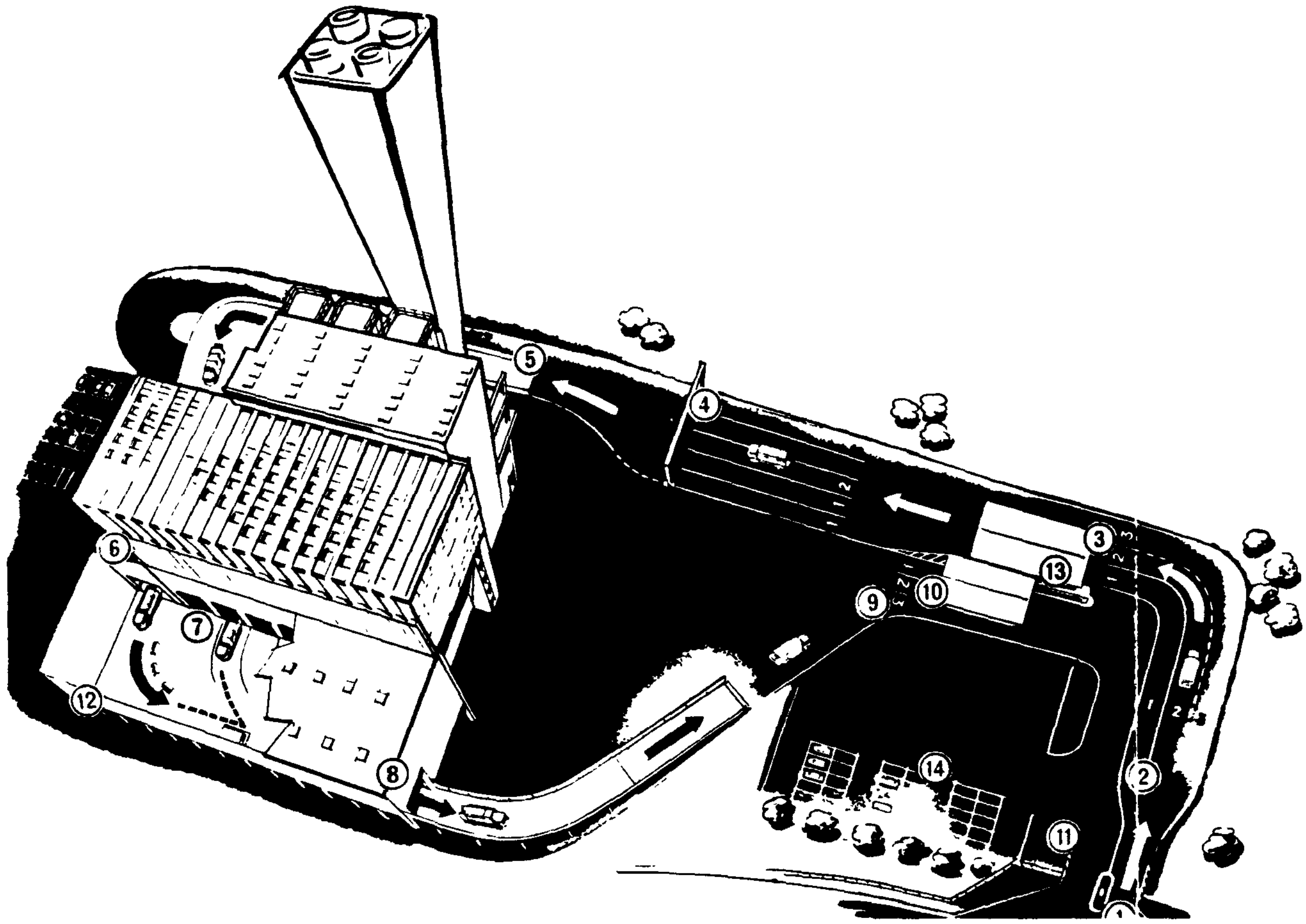


FIGURE 11-1. TOPVIEW OF SÄVENÄS WASTE-TO-ENERGY PLANT SHOWING TRAFFIC PATTERN, WEIGH STATIONS AND DISTINCTIVE SQUARE 4-FLUE CHIMNEY. ONLY THREE FLUES IN USE. CHIMNEY EQUIPPED WITH TWO-PASSENGER ELEVATOR. (COURTESY GRAAB)

1. Entrance gate - monitored by television.
2. Classification lanes for large and small trucks.
3. Weigh station.
4. Traffic control area.
5. Entrance ramp.
6. Entrance to enclosed tipping hall.
7. Bunker doors.
8. Exit door.
9. Exit lanes.
10. Exit weigh station.
11. Automatic exit gate.
12. Cafeteria (open 9 am to 2 pm).
13. Washroom (Drivers only)
14. Parking.

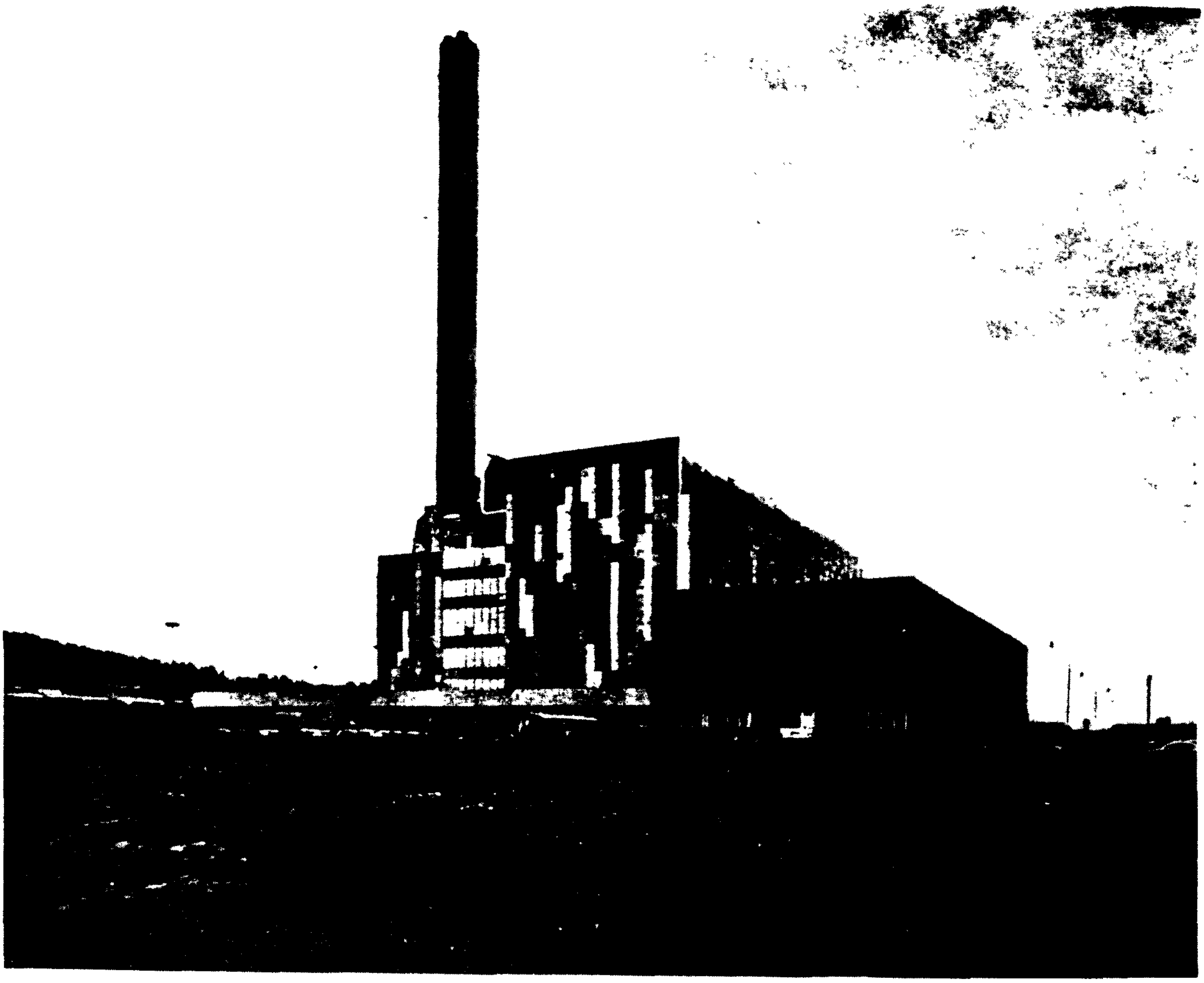


FIGURE 11-2. SÄVENÄS PLANT EAST OF GOTHENBURG. (Courtesy Von Roll, Ltd.)

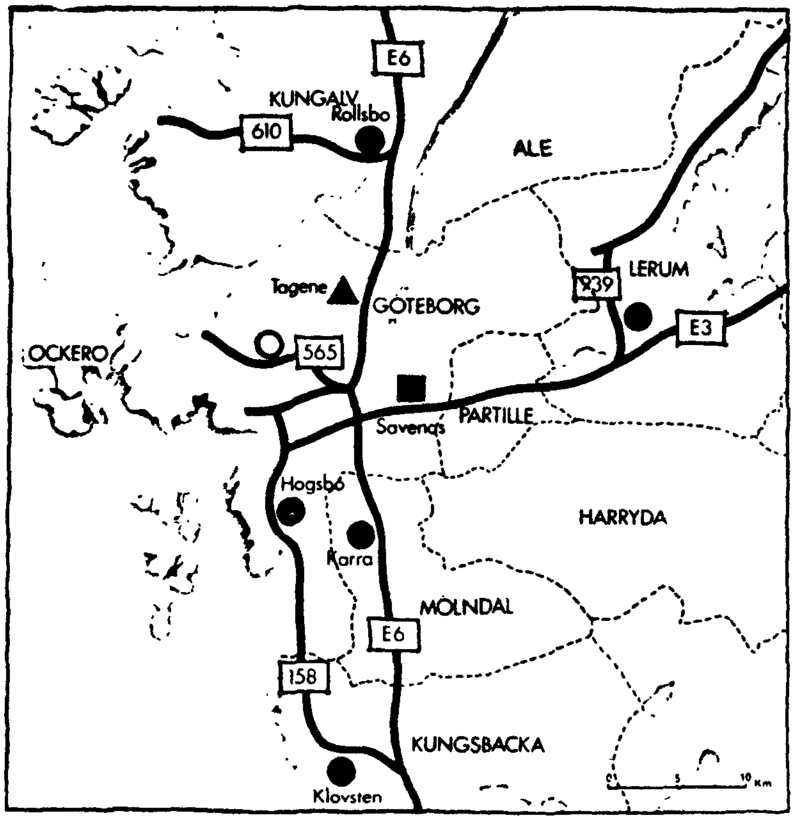
COMMUNITY DESCRIPTION

Gothenburg is a relatively "new" port city founded in 1619 on the hilly southwest coast of Sweden about 120 km (75 mi) across the Kattegat from the northern tip of Denmark. It is the most important industrial center in Sweden.

The Savenas plant is on the border of Partille adjacent to a large railway yard between the river Savean and the main highway to the east called Europawag 3. Figure 11-3 shows the area served which originally involved about 36 other towns. Owing to rapid consolidation of communities throughout Sweden, the number of towns now served is nine.

The Gothenburg population is 440,000. The total population served by the Savenas plant is 670,000. About 220,000 tonnes (242,000 tons) of refuse are received annually which is collected within a radius of about 17 km (10 mi) from the plant.

There are many manufacturing facilities in the area and a considerable fraction of the refuse received is industrial.



■ Sävenäs incinerator.

▲ New landfill at Tagene. (for ash only)

● Existing transfer stations.

○ Future transfer station

Dist. Sävenäs to Tagene ~6 mi.

FIGURE 11-3. COLLECTION AREA FOR GOTHENBURG WASTE HANDLING SYSTEM. TOTAL AREA SERVED IS ABOUT 1000 km^2 (386 square miles). (Courtesy of GRAAB).

SOLID WASTE PRACTICES

Solid Waste Generation

Refuse from the community residential, commercial, and industrial sources is received at the plant and at the five transfer stations shown in Figure 11-3. As of January, 1973, a separate facility, GRAAB-KEMI, was activated to receive chemical wastes.

Table 11-1 and Figure 11-4 show the proportions of waste received from the various sources.

Figure 11-5 shows the trend of weekly receipts of refuse for 1975 and 1976. The 15 to 20 percent drop in July and August reflects the effect of vacation time in Sweden.

Figure 11-6 shows the trend of total annual amount handled since 1972.

Solid Waste Collection

In 1971, the GRAAB organization established the first of five transfer stations and began acquiring specially-built transfer trucks as shown in Figure 11-7. The cylindrical chamber is 13.60 m (44.6 ft) long and 2.5 m (8.2 ft) in diameter, volume is 50 m^3 (538 ft^3), and overall height is 3.83 m (12.5 ft). Total weight is 33.40 tonnes (36.7 tons). Carrying capacity is 17.40 tonnes (19.1 tons). Overall length, including tractor, is 15.86 m (52 ft).

There are 30 of these transfer vehicles in the system bringing refuse to the plant from the five transfer stations. In 1972, each vehicle cost 250,000 skr ($62,500, 4 skr/$). Also, over 100 other trucks deliver directly to the Savenas plant. Total collections and deliveries to the transfer stations are made by the individual districts. There are about 300 truck loads per day delivered between 7:00 a.m. and 3:00 p.m., 5 days/week.

TABLE 11-1. SOURCES AND QUANTITIES OF REFUSE HANDLED IN 1976 FOR 53 WEEK PERIOD DECEMBER 29, 1975 TO JANUARY 2, 1977 (From 1976 GRAAB Annual Report)

	Ton	Population 1/1 1976	kg per person 1975	kg per person 1976
THE GRAAB-REGION				
Community				
Ale	5,100	22,000	234	232
Göteborg, incl. Öckerö	184,800	453,900	396	407
Härryda	5,600	20,700	304	271
Kungsbacka	8,600	38,400	220	225
Kungälv	8,700	28,300	297	307
Lerum	6,700	28,200	233	237
Mölndal	11,700	47,300	245	247
Patille	6,800	27,200	234	252
Private haulers				
Sävenäs plant	6,000	--	-	-
Hogsbo Transfer Station	1,900	--	-	-
Kungälv Transfer Station	200	--	-	-
Lerum Transfer Station	1,900	--	-	-
Mölndal Transfer Station	2,700	--	-	-
Kungsbacka Transfer Station	2,300	--	-	-
Total GRAAB region	253,000	666,000	374	380
Misc. haulers	800			
Total	253,800			

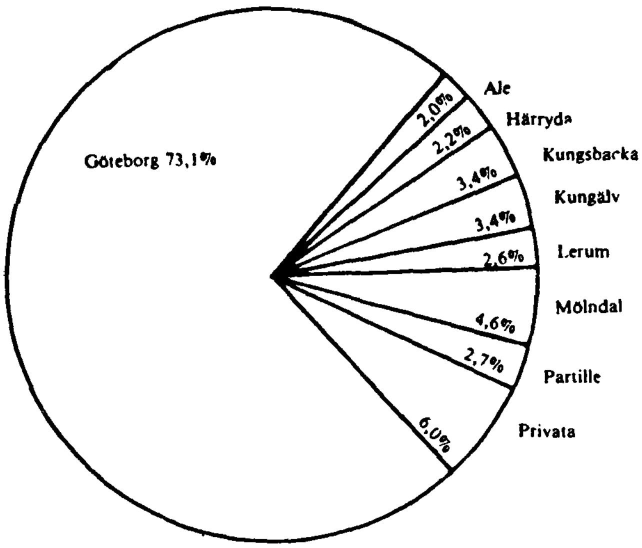


FIGURE 11-4. CHART OF DATA SHOWN IN TABLE 11-1.

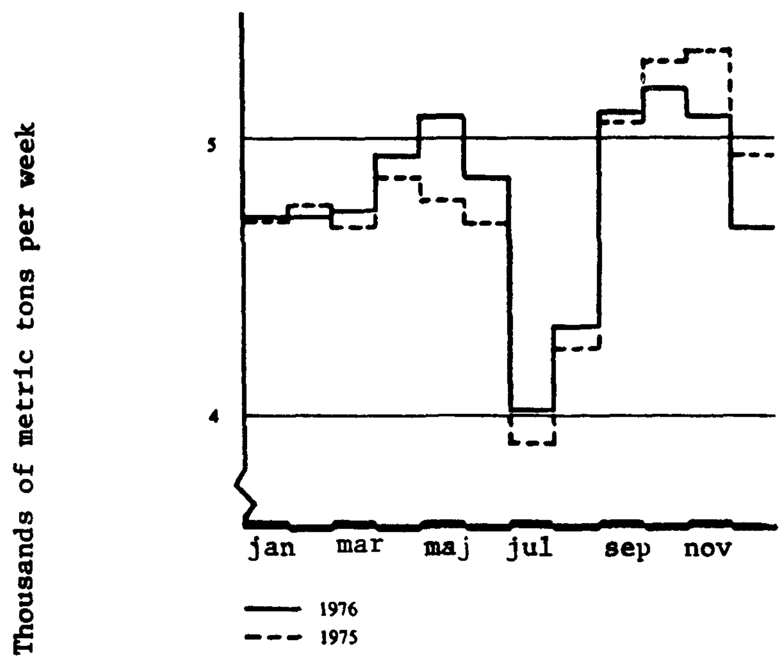


FIGURE 11-5. TREND OF WEEKLY RECEIPTS OF REFUSE FOR YEARS 1975-1976, THOUSANDS OF METRIC TONS. (From GRAAB 1976 Annual Report)

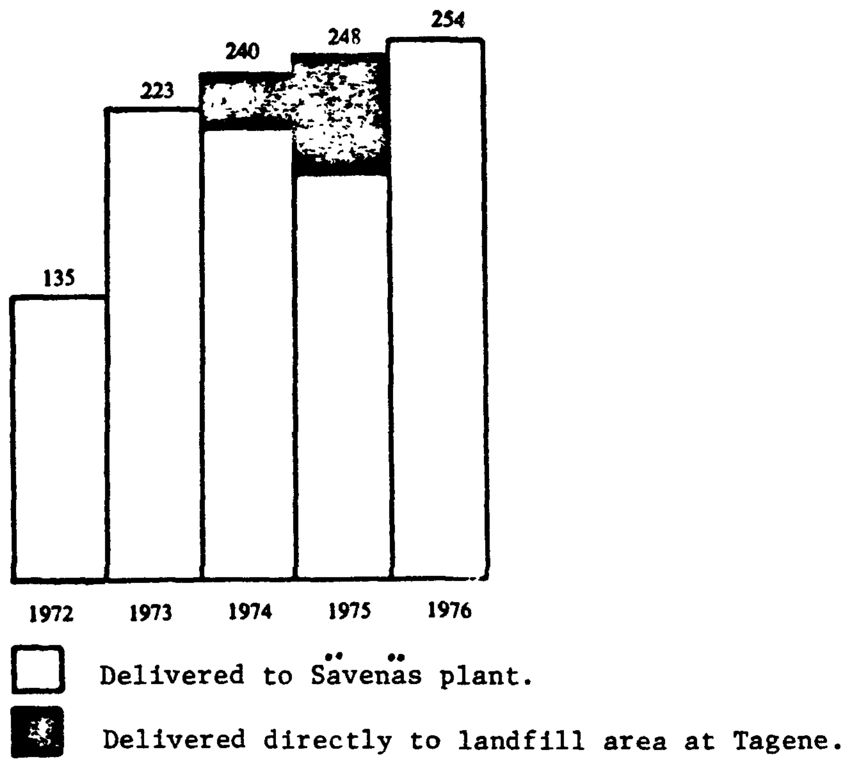


FIGURE 11-6. TREND OF ANNUAL TOTALS OF REFUSE HANDLED 1972-1976, THOUSANDS OF METRIC TONS. (From GRAAB 1976 Annual Report)

FIGURE 11-7. TRANSFER VEHICLE. THE CYLINDRICAL CHAMBER HOLDS ABOUT 50 m^3(1,765 ft^3) COMPRESSED AT THE TRANSFER STATION BY A FACTOR OF ABOUT 3.3 to 1 (Courtesy GRAAB)

Figure 11-8 shows one transfer station. The lower plan view shows two compactor trucks and one large truck delivering simultaneously to two hoppers.

Mr. Bengt Rundqwist, Works Director, described the operation of the system in a leaflet prepared for visitors in 1972:

> "The transfer stations are as centrally positioned as possible within each generation area in relation to local transport, since this method generally requires short distances for good economy. The central position requires high operational reliability to prevent health hazards. For the stations further away from the incineration plant, this means that irrespective of capacity requirements these are designed with double compactors , whilst the other stations are constructed as single stations.
>
> The waste is received basically in the same way and with the same type of weighing instruments and equipment as in the main plant. However, only one weighing machine is provided, which is why in tare weighing the vehicles must drive over the entrance weigher another time when leaving.
>
> Referring again to Figure 11-8, after weighing incoming refuse, the vehicles are backed into the emptying bay (1). The refuse is dumped into a funnel-shaped bunker with two pockets (2). Two compactors are placed under the bunker in the compactor room (3).
>
> In the unloading bay (4), trailer cars are coupled to the compactors, which force the refuse into the trailer containers against counter pressure. In the control room (7), a good view is obtained of the unloading and loading operations. From here, everything happening inside and outside the plant can be monitored. A station equipped with two compactors has a capacity of about 50,000 tons/annum and costs about 2 million kronor ($500,000 @ 4 skr/$).

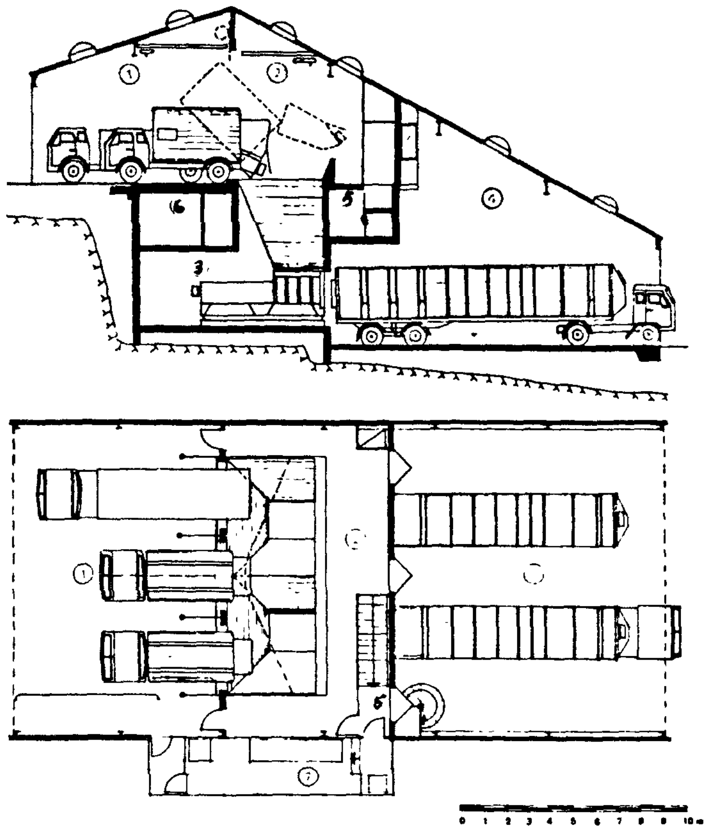


FIGURE 11-8. CROSS SECTION AND PLAN VIEW OF TRANSFER STATION. (Courtesy GRAAB)

1. Tipping Hall
2. Bunker
3. Compactor
4. Vehicle Hall
5. Stairway
6. Washroom
7. Control Room

The transfer trailer is equipped with a hydraulic plate which, when loading, serves as a back-stop to obtain correct load distribution and compression ratios (about 1:3). On emptying--which takes 4 to 5 minutes--the plate serves as an explusion plate."

Solid Waste Disposal

Noncombustibles, incinerated residue, and sewage sludge go to the new Tagene sanitary landfill about 10 km (6 mi) from the Savenas plant.

DEVELOPMENT OF THE SYSTEM

Prior to 1971, about 10 percent of the refuse disposal in the region was handled in 10 small local incinerators, seven of which recovered heat for district heating and the rest went to uncontrolled landfills. Air pollution from the incinerators was sometimes a problem. In 1955, discussions began of better ways of doing it. The concensus developed that a central facility would be desirable but siting was difficult. At one point, consideration was given to building some large landscaped hills of refuse as is now being done at the Hogdalen plant just south of Stockholm.

Mr. Bengt Rundqwist, who was quoted earlier, wrote in 1972:

"According to a special report on refuse prepared by the Greater Gothenburg Cooperation Committee in 1965, the 23-member districts formed a community of interests, Goteborgsregionens-Avfallsaktiebolag-GRAAB, with the task of solving associated problems.

The responsibilities of the districts and the regulations governing cooperation were laid down in a consortial agreement valid for a period of 30 years. The agreement describes the method whereby expenses shall be calculated, stipulates that costs for refuse treatment shall be the same throughout the region when the refuse is deposited at the incineration plant or any of the transfer stations, and how the shares amounting to 4.5 million kronor and the bonds amounting to 120 million kronor shall be distributed.

GRAAB also played a leading part in constructing GRAAB-KEMI, a receiving station for chemical wastes. This consists of a chemical storage, toxic storage, and an oil reception plant. Furthermore, a wet chemical line was planned with the task of treating diluted solutions and those chemicals which are unsuitable for storage. The wet chemical line will form the basis for decisions on the region's own treatment plants. The operation of this reception station is also GRAAB-KEMI task. The company has equipment for work in practically the entire chemical refuse sector. Detailed discussions were held with the Gothenburg Cleaning Dept., GRAAB on the company's cooperation within the monopoly as a whole, which began to operate the Gothenburg district in January, 1973."

GRAAB also installed a cremation furnace for dead animals.

Although at the beginning of the discussions, 36 communities were involved. Later, consolidation of communities, which has been nationwide, reduced the number first to 23, then to 13, and now to nine large communities. These are all involved in GRAAB. Some of these extend partly into other counties. They have ownership in the entire system as follows:

	Shares	Percent
Ale	1,530	3.4
Goteborg	33,396	74.2
Harryda	762	1.7
Kungsbacka	1,239	2.8
Kungalv	2,034	4.5
Lerum	1,101	2.4
Molndal	3,066	6.8
Partille	1,551	3.5
Ockero	321	0.7
TOTAL	45,000	100.0

The nine communities are represented on a Board of Directors, which meets 10 times/year. A working committee of the Board meets about twice a month.

Beginning of the Savenas Facility

Eight bids were received in 1967 for the Savenas plant. Von Roll, Ltd. was selected because, although it was not the lowest bidder, it appeared to have experience with many similar large plants and had built or was building plants at Linköping, Bollmora, and Umea in Sweden.

In 1965, the estimated price was 65 x 10^6 skr (\$16.25 x 10^6 @ 4 skr/\$).* The contract was signed in October, 1969. By the time the plant and its ancillary stations were built in 1972, the total cost had risen to 120 x 10^6 skr (\$30 x 10^6 @ 4 skr/\$). This included five transfer stations, trucks, Tagene landfill and the transport equipment for residue and sewage sludge. Three boiler-furnace units were installed with building space provided for a fourth unit.

Inflation was the primary cause of the increase in cost although the national environmental authorities caused some increase by requiring some enlargement of pollution control equipment. GRAAB management feels that 88 percent of the increase was beyond their control. For example, unexpected clay under the site required 3,000 m more piling than expected. For this same reason, the refuse pit is not as deep as planned.

Normal plant operation began March 1, 1972. It operates 7 days/week.

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* The report uses two monetary conversion factors: (1) 1965 to 1972 estimates, bids, capital investment costs, etc. @ 4 skr/\$; and (2) 1975 to 1977 expense and revenue figures @ 5 skr/\$.

PLANT ARCHITECTURE

The plant structure was designed by the Gothenburg firm of Sten Ericssons Arkitektkontor AB. As seen earlier in Figure 11-2, the main plant facade presents an unusual aspect produced by random vertical strips of different colors of anodized aluminum panels.

Figure 11-1 has earlier shown the plot plan with ample roadways for orderly traffic flow.

REFUSE-FIRED STEAM GENERATOR

Heat Input

Because of the considerable industrial activity in the Gothenburg region, the lower heat value of the refuse is comparatively high. At present, it is estimated to average between 2,600 and 2,700 Kcal/kg (4,689 to 4,870 Btu/lb) (10,885 to 11,304 kJ/kg). Estimated moisture content is about 23 percent. Design figures in 1967 were 15 t/h and 2200 kcal/kg=33Gcal/h. Plant staff are certain that when the plant started in 1972, the heat value was even higher because then it was found difficult to burn more than 12 tonnes/hr without overheating the boilers, but now it is possible to burn 15 tonnes/hr. This apparent trend in heat value of Swedish refuse is borne out by data published by Feindler (1) for Stockholm as follows:

	Lower Heat Value		
	Btu/lb	Kcal/kg	kJ/kg
1964	3,546	1,970	8,248
1965	3,942	2,190	9,169
1966	4,050	2,250	9,420
--	--	--	--
1971	4,545	2,525	10,572
1972	4,950	2,750	11,514
1973	4,680	2,600	10,885
1974	4,500	2,500	10,467
1975	4,410	2,450	10,158

A puzzling contrast with these values are the comparative maximum lower heat values at Duesseldorf, a highly industrialized area, through 1972 to 1975, of only 1,800 Kcal/kg. Their average values were 1,700 Kcal/kg.

It is likely that Gothenburg's refuse reached a higher peak in 1972 than the value shown above for Stockholm because of the probably higher proportion of industrial waste. Plant staff surmise that the reduced heat value at Gothenburg in recent years has occurred because of increased Swedish activity in paper recycling. In all of this discussion of heat values, it must be borne in mind that it is notoriously difficult to obtain reliable samples of heterogenous refuse for analysis. Small differences in heat values are not significant.

If the high values at Stockholm from 1971 to 1975 were actually exceeded at Gothenburg, this would help to explain some of the difficulties experienced in 1972 and 1973 with furnace tube failures to be discussed later. However, later it will be shown that the weight ratio of steam produced to refuse fired is still (1976) relatively high at Gothenburg and still increasing slightly every year which indicates a continuing high heat value of refuse.

Weighing Operation

All refuse is weighed at the entrance to the plant area shown earlier in Figure 11-1. The weighing procedure is automated whenever possible. Most suppliers use customer cards and need no service therefore.

The weighing plant is equipped with four electronic weighing machines and a data recording system, which, besides supplying continuous information to operational management, also enables automatic debiting and invoicing to be carried out. In addition, statistical information is received. Traffic inside the area and the emptying bay is monitored by a traffic controller--stationed in the emptying bay--who directs arriving vehicles by means of TV and traffic signals. In low traffic periods, monitoring can be transferred to the central plant control room. Incoming vehicles pass to the closed emptying bay via ramps, the bay being separated from the waste bunker by 14 bunker gates. After emptying, the vehicles again pass the weighing room where tare weighing is carried out on certain vehicles and where any cash is paid.

The weighing equipment and data system have required little servicing, an estimated down-time of once per year. The scale is of Swedish make, by Stathmos. The data system is by General Automation Co. of Anaheim, California, U.S.A.

Provisions to Handle Bulky Wastes

When the crane operator stationed in the podium near the top of the bunker observes oversize waste being delivered, he can lift it to one of two Von Roll Model 13/310 shears situated between two of the furnace feed hoppers to have it cut to smaller size. The cut pieces fall from the shears into the refuse pit. The rated shear capacity is 120 m^3/hr.

Refuse Storage and Retrieval

Figure 11-9 shows a transfer truck backing toward an open pit door to which the driver has been directed by signal lights.

Figure 11-10 shows a cross-section of the Savenas plant. The pit extends 9 m below the tipping floor. It holds approximately 6,000 m^3 (7,843 yd^3). By closing half of the 14 bunker doors and piling the waste high against the opposite wall, the storage capacity can be doubled.

The pit is served by two bridge cranes built by Kone with capacities of 11,4 and 4,8 f net. weight. One has a polyp-type bucket of 6m^3 capacity.

Figure 11-11 shows the pit with two of the 14 doors open to receive waste. The two crane operators can be seen in the glass walled podium in the upper right. Beneath them is a platform supporting a high-pressure water cannon which can inject water at 1 m^3/min for control of pit fires. Because of a dangerous fire when two drums of solvent were cut open in a shear, new foam nozzles have been added at the pit sides which can cover the pit with foam 1 m deep in 10 minutes

The weight of refuse in each bucket load is read from two calibrated watt meters on the cranes with digital readout in the crane podium and readout and recording in the control room. The total weights are checked frequently against the truck scale totals. The watt-meter weights are claimed to be accurate within 5 kg (11.1 lb).

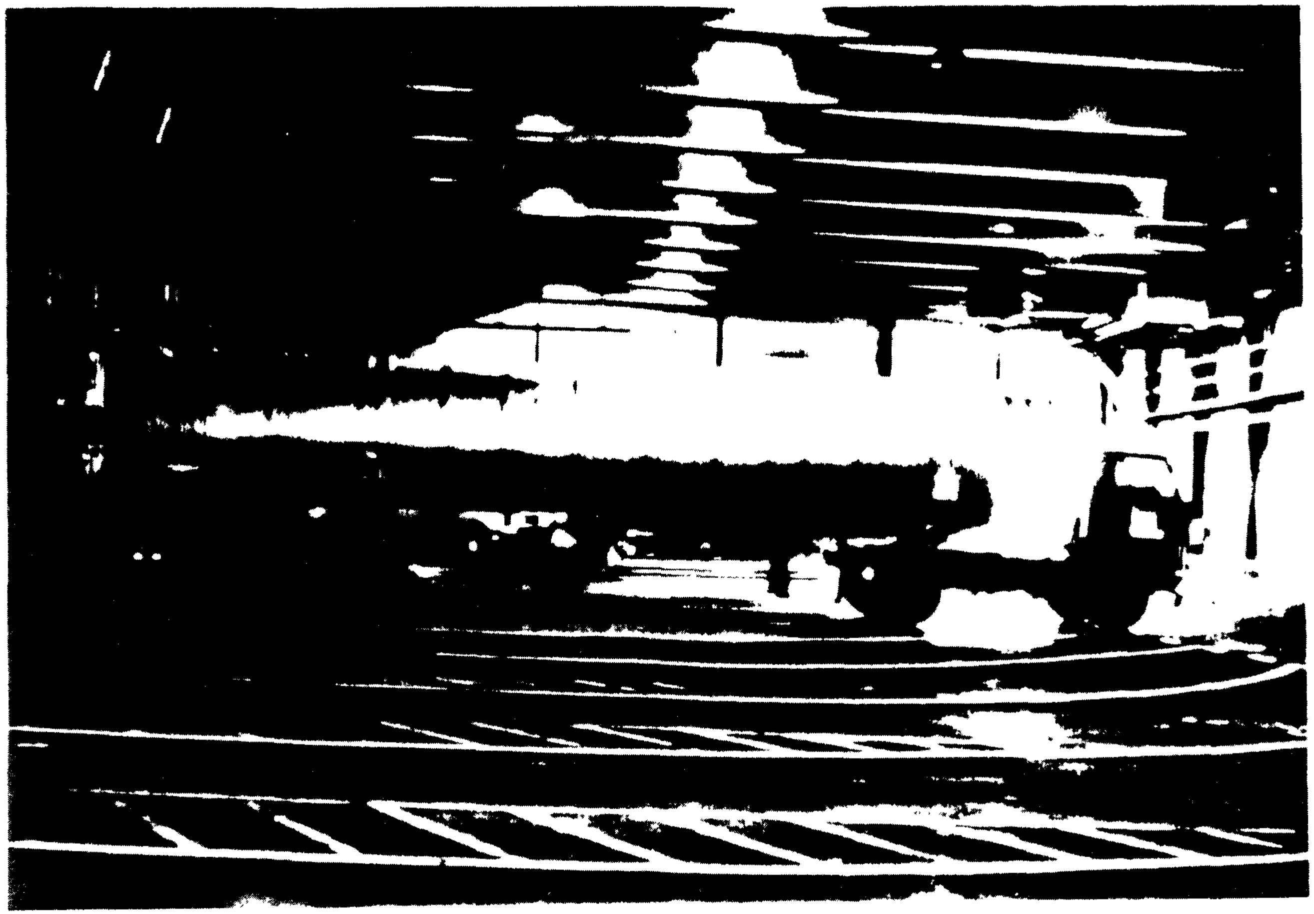
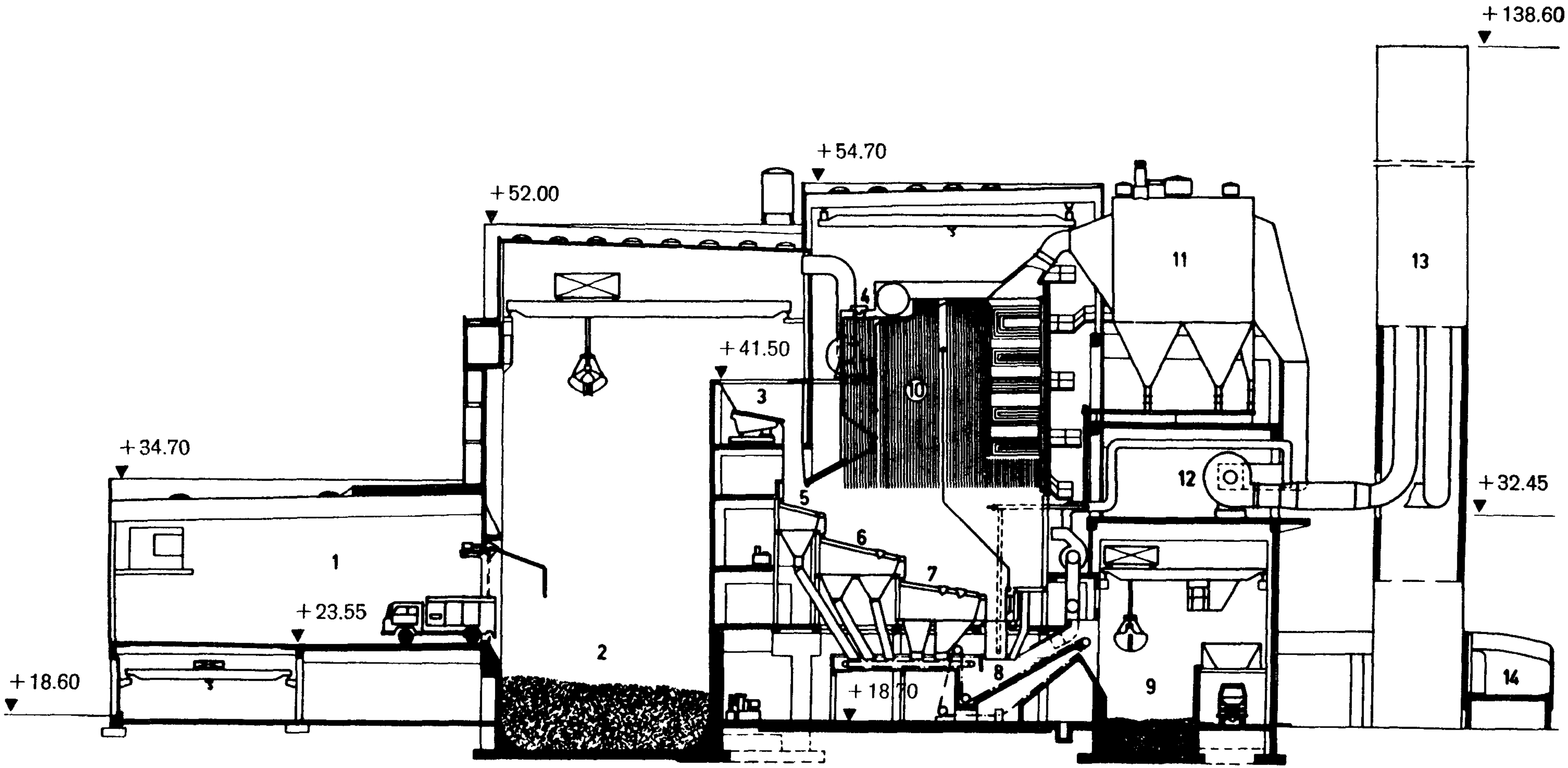


FIGURE 11-9. TRANSFER TRUCK IN UNLOADING POSITION AT SAVENAS PLANT
(Battelle Photograph)



1. Tipping hall
2. Refuse pit
3. Feed hopper and vibrating feeder
4. Oil burner
5. Reciprocating feed grate
6. Burning grate (Q-L system)
7. Burnout grate (Q-L system)
8. Residue conveyor
9. Residue bunker
10. Boiler
11. Electrostatic precipitator and multicyclone collector
12. Induced draft fan
13. Chimney
14. Entrance ramp
15. Forced draft tan (primary air)
16. Secondary air fal

FIGURE 11-10. CROSS SECTION OF NOMINAL 900 TONNE PER DAY. REFUSE FIRED STEAM-TO-HOT WATER HEATING PLANT AT SÄVENÄS, GOTHENBURG. PLANT STARTED UP MARCH 1, 1972. (Courtesy of GRAAB).

FIGURE 11-11. REFUSE PIT WITH 2 OF THE 14 DOORS OPEN TO RECEIVE REFUSE (Battelle Photograph)

To reduce crane cable wear, the cable drums have been enlarged to 24 times the wire diameter and wire size has been increased from 23 to 27 mm (0.9 to 1.1 in).

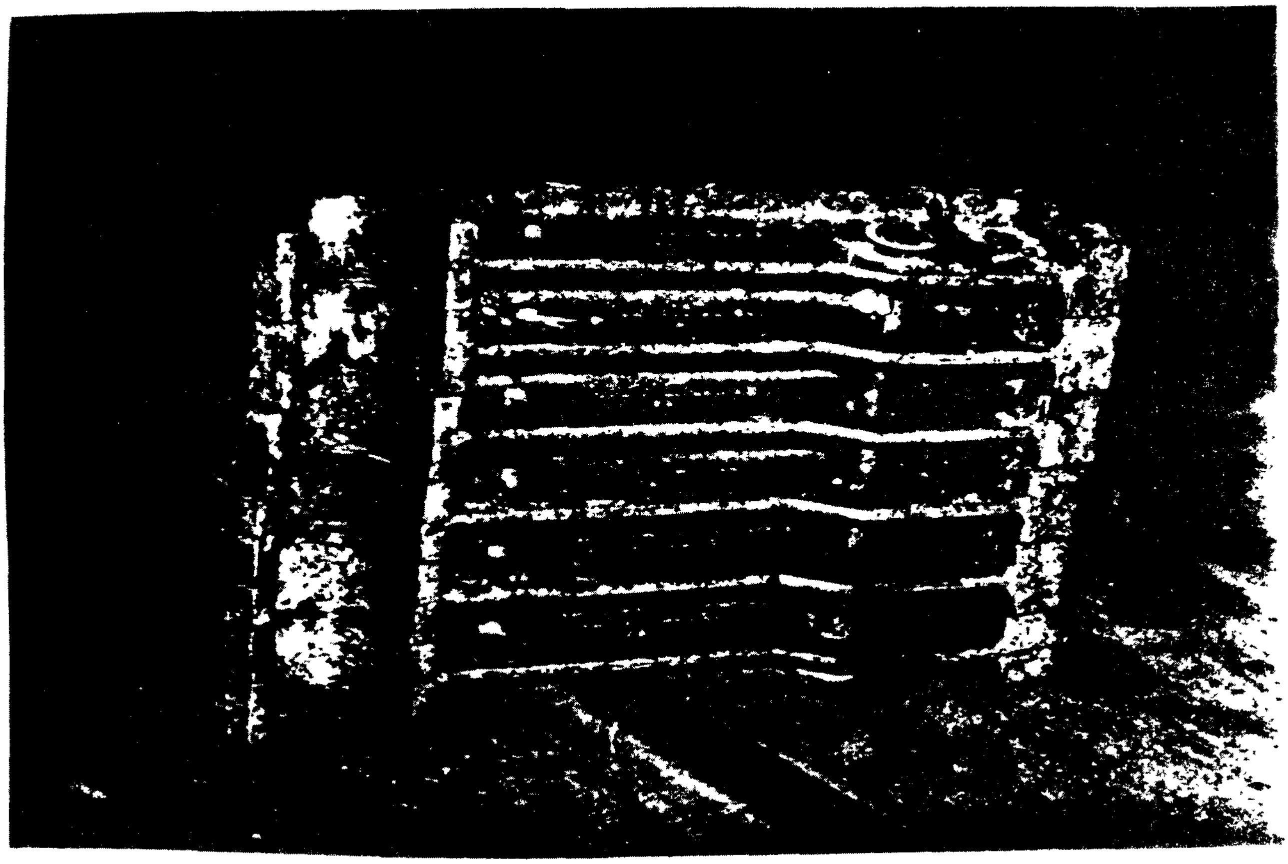
Furnace Hoppers and Feeders

The top of the three furnace feed hoppers is 3.5 by 2.5 m (11.5 by 8.1 ft) each. At the hopper bottom is a sloping vibrating table built by Schenk and having an amplitude of 8 mm (0.3 in). The feeders are controlled by radioactive level indicators in the water-cooled feed chutes. The indicators use radiation from Cesium 136. They were made by Endress and Hauser of Lorrach, Germany.

The vibrating feeder has been satisfactory. The chief engineer pointed out that the use of a vibrating feeder to feed the vertical chute 1.2 by 3.4 m (4 by 11 ft) requires about a 3 m (10 ft) height of refuse in the chute to assure a tight air seal and avoid burnbacks in the chute. If a hydraulic ram feeder were used just above the grate to maintain a seal, apart of the 10-ft chute height could be eliminated, thus reducing overall building height by about 1-2 meters. However, the tall chute does provide a simple, easily managed seal that has effectively minimized burnback.

Burning Grate

From the chute, the refuse falls on to a Von Roll reciprocating /transversal feed grate which drops it down along a refractory wall to the main burning grate. The feed grate is 2.625 m (8.6 ft) long and 3.4 m (11.2 ft) wide. The length of the main grate and outburning grate is 5.425 m (17.8 ft) each and their width is alsc 3.4 m (11.2 ft).



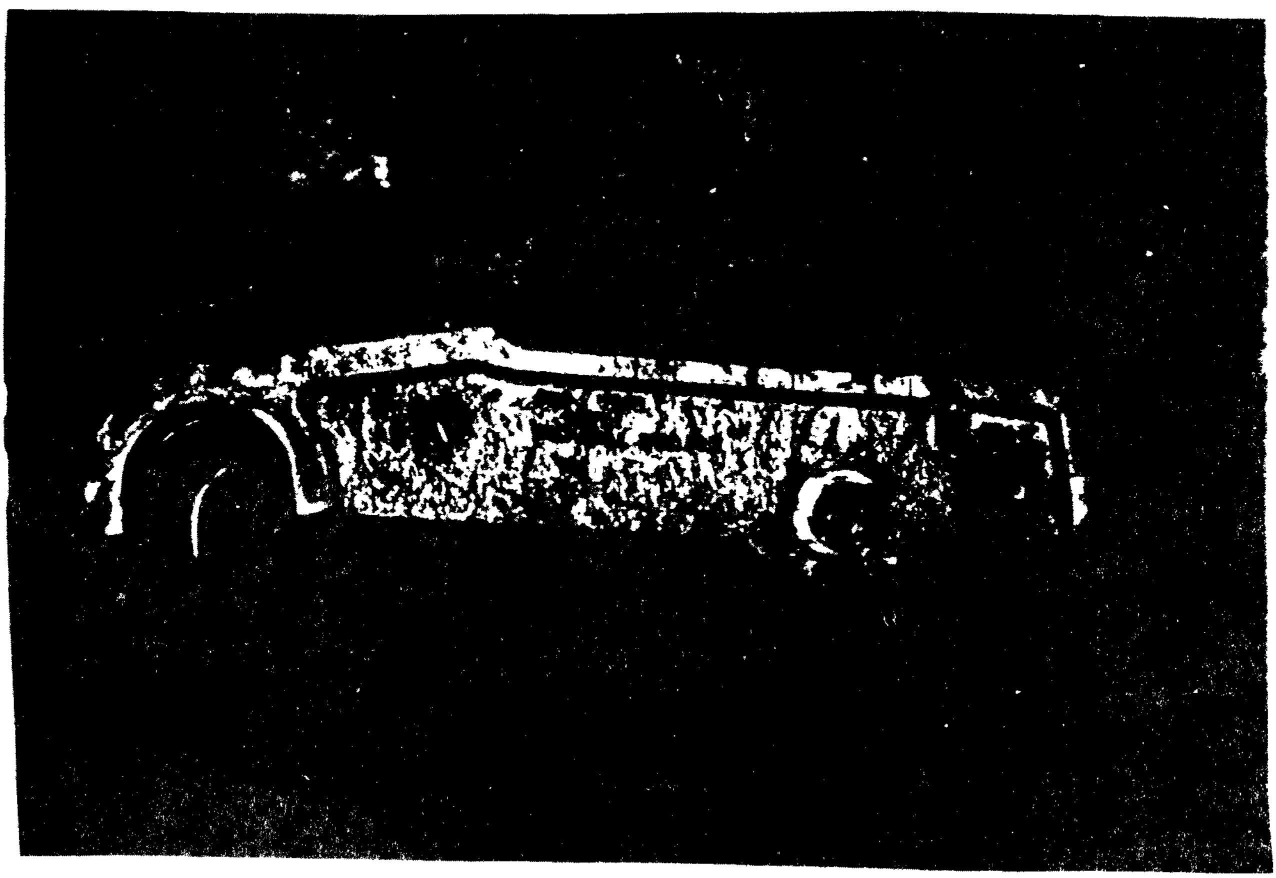


FIGURE 11-12a. TWO VIEWS OF NEW Q-L TYPE GRATE BAR
(Courtesy Von Roll)

Figure 11-12 shows a view upward into one of the furnaces. The main burning grate in the foreground carries some clinker. Above the cooled refractory grate step wall in the rear of the platform (front of the furnace) is the feed grate. Secondary combustion air introduced through the cooled refractory step wall to improve the distribution of combustion. The slag shown on the wall will be discussed later.

The burning and burnout grates have a total area of 36.9 m^2 (397 ft^2). For a nominal daily throughput of 300 tonnes/day, this provides an average burning rate of 339 $kg/m^2/hr$ (69 $lb/ft^2/hr$). At the maximum throughput of 360 tonnes/day, the burning rate increases 20 percent to 407 $kg/m^2/hr$ (83 $lb/ft^2/hr$). These are moderately high rates which, with unusually "hot" refuse, could require maximum furnace cooling to avoid slag melting problems.

In Figure 11-10, introduced earlier, grate "knives" are shown in both burning grates which were intended to break up the fuel mass and allow better air distribution. Because of maintenance problems, and no need of them anymore with the high lower heat value, these have been removed successively. The new Q-L grate is shown on enclosed photos.

The original grate was the early style Von Roll grate in which alternating rows of grate bars reciprocate causing rapid wear on the sides of the bars. The design clearance between bars was 2 or 3 mm (0.080 to 0.18 in). After 25,000 hours, this had increased to 15 m (0.59 in) at the tops of the bars. This allows unburned material and ash to drop through and inhibits firm control of the distribution of primary air flow. Von Roll feels that much of the wear was caused by abrasion from small, hard steel machine screws and similar matter which come in the industrial wastes. With the new grate, the undergrate air pressure is 110 to 120 mm water (1.08 to 1.18 k Pa). With old worn grates, it was only 30 to 50 mm (0.29 to 0.4 k Pa)

The feed grate has been no problem. Sixty to 70 percent of the main burning grate bars had to be replaced over a period of 5 years. The burnout grate bars required some replacement but only toward the upper end near the drop from the main grate. The cost of grate repairs over 5 years was about 250,000 to 300,000 skr ($50,000 to $60,000).

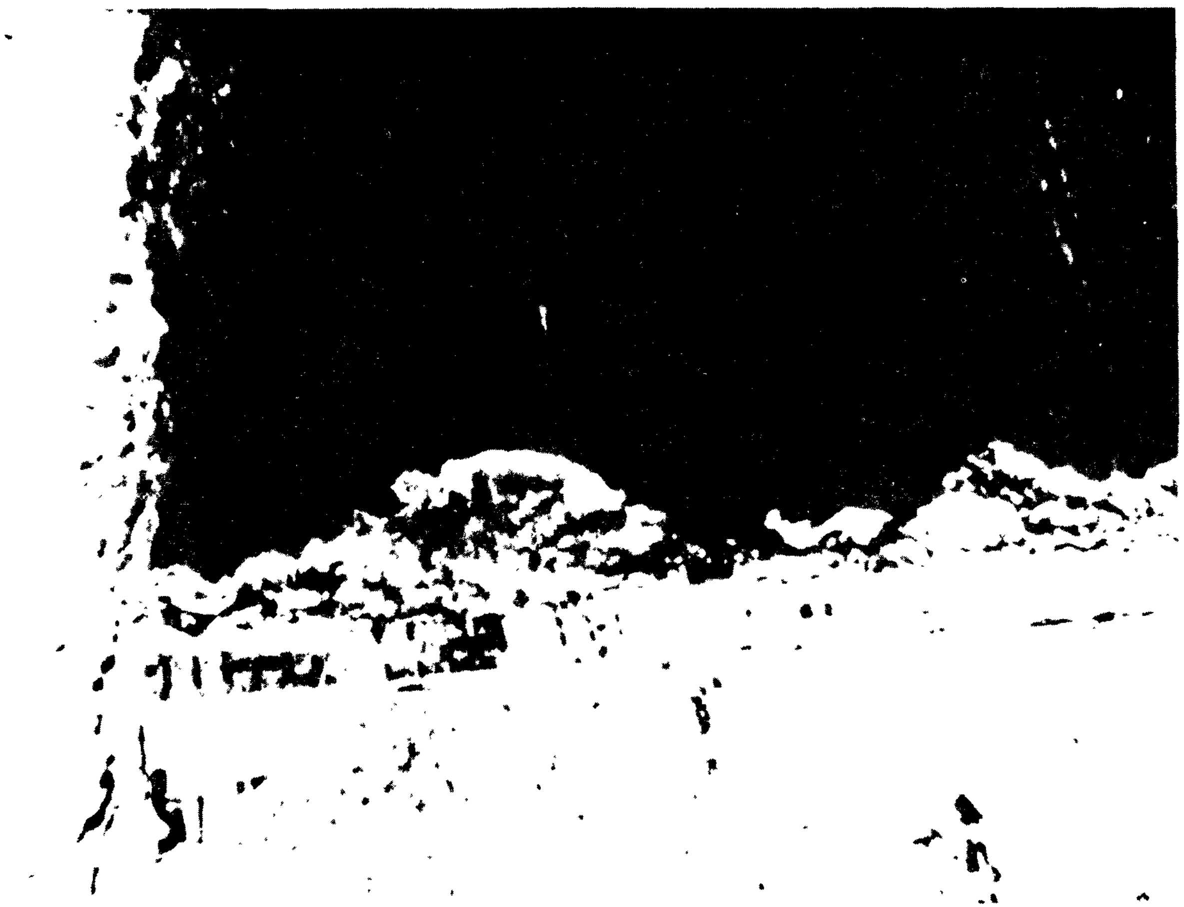


FIGURE 11-12. VIEW FORWARD IN FURNACE SHOWING TWO GRATE STEPS AND SLAG ACCUMULATION ON WALL AT LEFT (Battelle Photograph)

In 1973, after 2-1/2 years of operation, a test showed 3 percent unburned carbon in the residue. The guarantee was 7 percent. Guaranteed putrescible content was 0.3 percent. Actual content was 0.04 percent. These results would indicate good combustion at that time. Nevertheless, because the wear of grate bars would continue, in December, 1976, the old grate in Boiler 3 was replaced by the new Von Roll arrangement where each transverse assembly of grates reciprocates in unison, thus eliminating the wear from relative motion between adjacent bars. Similar replacements were made on Boilers 1 and 2 between June and August, 1977. The basic undergrate construction remains the same.

Furnace Wall

Referring back to Figure 11-10, showing the plant cross section, it can be observed that most of the main furnace is not water-tube walled but is refractory, 0.58 m (1.9 ft) thick. In the upper part of the combustion chamber, the front and rear arch surfaces are partially covered with a castable refractory lining, applied on special studys as a protection against the furnace gases. The water tube front wall is seen to begin near the top of the furnace at about the level of the top of the refuse feed entrance. The carbon steel tubes are tangent welded, 76 mm (3 in) in diameter and 4 mm (0.16 in) thick.

The front and rear walls are spaced water tubes covered with cast. Above the nose of the front wall can be seen a separate water-tube-walled combustion chamber for burning oil. Half of the rated heat output of each boiler can be generated using low-sulfur, No. 5 fuel oil.

Although these boilers generate saturated steam at only 22 bar (323 psia) (2,229 Pa) and 217 C (423 F), which is well below the usual tube-corrosion threshold, the lower one third of the water-tube walled first pass was equipped with welded studs holding in place a 50 mm (2 in) thick layer of high alumina plastic refractory. This was a successful effort to protect those tubes from chloride attack, which occurs when the chlorides deposited against the tube metal and sealed in by other ash deposits became hot enough to decompose under the reducing conditions existing within the deposit, thus liberating chlorine which attacks the tube metal.

As already stated, the alumina covering over the lower one third of the first pass was successful in protecting those wall tubes, but in July, 1975, immediately above that coating, a tube began to leak in Boiler 2 after 20,830 hours of operation. Three weeks later, a similar leak appeared in Boiler 1. Up to that time, no routine checks had been made of tube thickness. After that experience, checks have been made twice a year at specific locations throughout the boiler. The wastage rates in the first and second passes now range between 0.1 and 0.2 mm per year (0.004 to 0.008 in).

In retrospect, it now appears that the tube wastage was caused by the following:

- High refuse input rates
- High heat value of refuse
- Uneven distribution of air and combustion
- Excessive soot blowing.

Originally, each boiler was equipped with 21 soot blowers. There were two sets in the first pass. Although the plant is for district heating only (hence, does not need high-temperature steam), a small superheater was placed in the third pass to generate superheated steam up to 300 C (572 F) for soot blowing only. When the soot blowers were not in use, the superheated steam was condensed in a heat exchanger in the boiler drum. The soot blowers thus were assured of dry steam so as to avoid any erosive impact on the boiler tubes by water droplets. However, they probably cleaned the tubes too well and too often with the result that the bare tubes were exposed to corrosion and probably erosion. In 1974, it had been first noted that the first pass blowers were cleaning exceptionally well. Accordingly, 11 of the 21 blowers have now been removed and the 10 remaining are used once per shift.

Another change was to add more refractory coating above that originally in the first pass. That was done in three successive steps until the coating extended upward to cover the lower two thirds of the first pass water-tube wall.

Figure 11-13 shows more changes that were made at GRAAB expense to reduce tube wastage. The 18 sidewall air jets on each side just below the wall tube header were blocked and replaced by downward angled jets in front and back. Also, a rear nose formed of refractory-covered tubes was added to direct the flame flow away from the rear wall. A sloping dotted line above that rear nose shows how the slope of the tubes was later modified to discourage buildup of loose ash deposits. Also, later the location of the rearwall jets was moved farther forward toward the top of the nose. The first rear wall nose was installed in Boiler 2 in December, 1975 (Week No. 48). The second was in Boiler 1 in March, 1976 (Week No. 10). The third was in November, 1976 (Week No. 46).

These measures plus the apparent reduction in refuse heat value have reduced the tube corrosion rate to a point where plant staff estimates that 30,000 hours of operation can be expected before some tube replacements may be needed.

The cost of the boiler-furnace repairs and modifications in 1975 was about 5 million skr ($1 million). Ordinarily the staff expects repairs to cost 10 skr/tonne.

Some wastage has occurred in the roof tubes of both the first and second pass. This is being countered by a sprayed-on coating of silicon carbide about 8 mm (0.31 in) thick. The same coating has been sprayed opposite the soot blowers in the second pass. The durability of this coating appears good after 1 year but has not yet been fully determined.

Ten sections of alloy-clad steel tubes are being tried in the upper middle position of the wall of the second pass. These "sandwich" tubes, made by Sandviken, have a wall thickness of 7.1 mm (0.28 in) coated with an extruded stainless steel layer 1.6 mm (0.063 in) thick. Although these tubes cost 10 times as much as carbon steel tubes, experience with an

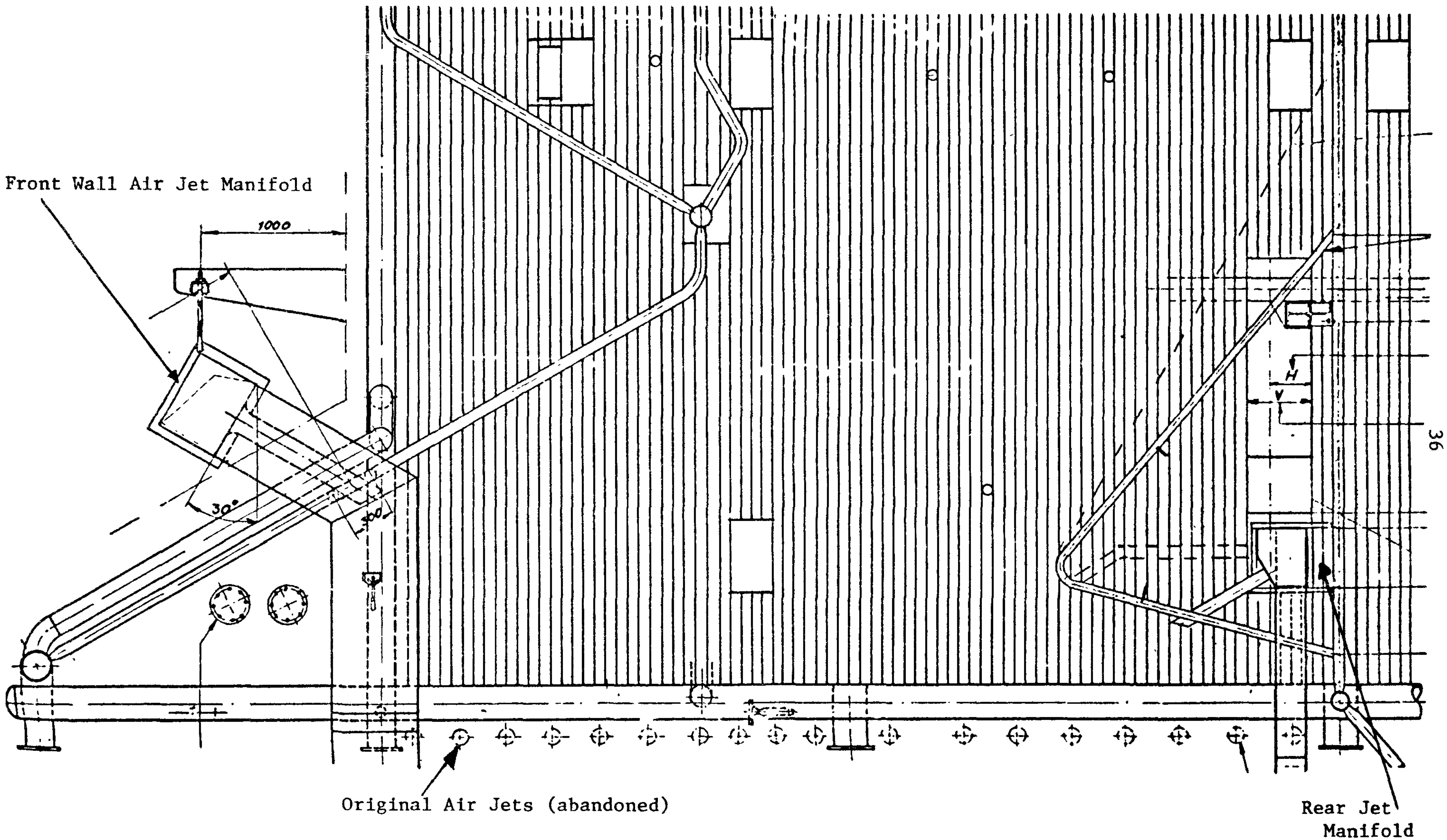


FIGURE 11-13. LOWER PORTION OF FIRST PASS SHOWING 18 ORIGINAL SIDEWALL JETS, NOW ABANDONED, REAR NOSE FORMED OF REFRACTORY COVERED BENT TUBES, AND MANIFOLDS FOR NEW FRONT AND REARWALL SECONDARY AIR JETS AIMED DOWNWARD ABOUT 30 DEGREES. (Courtesy GRAAB)

entire pass formed of these tubes at the Hogdalen plant built by Vereinigte Kesselwerke south of Stockholm indicates that for conditions at that plant they are worth it in minimizing tube wastage.

To monitor first pass gas temperature, thermocouples have been placed about 7 m (23 ft) above the grate.

In the third pass which contains the boiler convection sections and superheater, some tube erosion by soot blowers has occurred. This was first countered by means of alloy half-round shields 1 mm (0.04 in) thick made of Swedish steel designated 23-43. The shields were tack welded to the tubes directly opposite the soot blowers. For simplicity, these were later replaced by alloy angle irons strapped to the tubes. The angles are made of 20 percent chromium and 10 percent nickel steel. This material costs 40 skr/kg ($3.60/lb). They are fully successful in protecting the tubes from soot-blower action and appear to survive about 6 months before needing replacement.

Second Pass

All of the wall coatings, roof coatings, and convection-bank shielding have impaired somewhat the total boiler heat absorption. To counter this loss, it is planned shortly to install in the second pass three vertically suspended plattens of water tubes to increase heat absorption in that pass

Furnace Heat Release

Von Roll considers the entire furnace and first pass as effective combustion volume which it estimates at 310 m^3 (3,336 ft^3). However, if only that two thirds of the pass which is now refractory coated is considered as part of the combustion volume, we estimate this volume, together with the furnace, is 263 m^3 (2,830 ft^3). In this smaller volume, with 300 tonnes (330 tons) per day being burned having a lower heat value of 2,500 Kcal/kg (4,500 Btu/lb) (10,467 kJ/kg), the volume heat release rate is approximately 118,821 Kcal/m^3-hr (13,325 Btu/ft^3) (498 mJ/m^3-hr). These are moderately high heat release rates.

Figure 11-12, discussed earlier, showed some evidence of slag accumulation on the refractory walls. As changes were made in wall-tube coatings and secondary air direction, this slag appeared to accumulate higher up on the walls. Some thought is being given to the possible use of air-cooled wall blocks low in the furnace to help alleviate this problem.

Superheater

As explained before, the only reason for a superheater in this heating plant is to provide dry 300 C (572 F) steam for the soot blowers. It is formed in two in-line banks of 35 tubes of carbon steel designated as composition 35.8. These tubes are 32.8 mm (1.25 in) in diameter and 3 mm (0.118 in) thick. The two banks are located in the lower portion of the third pass just after the first convection bank.

Some erosion of the superheater tubes was caused by fly ash concentrating against the wall of the third pass. This has been countered by steel shields on the tubes where they pass through the wall.

Boiler

The three boilers are of the Eckrohr type built by Generator AB of Gothenburg under license from Dr. Verkauf of Berlin. Rated steam capacity is 52.5 tonnes/hr (115,500 lb/hr) of saturated steam at 22 bar (313 psia) (2,157 kPa). Overall height is 13 m (42 ft), width is 4.5 m (14.8 ft), and depth is 15.5 m (51 ft). There is no economizer.

Primary Air

Originally there was a steam-to-air preheater and a tubular flue-gas to air preheat. The steam to air preheater has been removed in 1974-75.

The tubular flue gas to air preheater will be removed, the first unit (No. 3) in September 1978 as the heat value of the refuse is so high that preheated air is unnecessary.

The primary air is drawn from the front of the tipping floor and passes the bunker to the inlet. The blowers were made by Svenska Flaktfabriken. Maximum blower capacity is approximately 90,000 Nm^3/hr (34,718 scfm) at 400 mm water (3.9 kPa) maximum pressure. The original air preheat was 250 C (482 F) but this is being discontinued as unnecessary. The air originally went to five zones under the grates, but the air to the feed grate has been stopped, so there are now four zones, manually controlled.

Secondary Air

The three secondary air blowers can each deliver 33,000 Nm^3/hr (19,420 scfm) at 280 mm water (2.74 kPa).
The estimated velocity in the air nozzles is 35 m/sec (115 fps). As explained earlier in connection with Figure 11-13, the 18 jets on each side were replaced by seven jets in the front and nine in the back. All of these are 80 mm (3.1 in) in diameter except three larger ones in the front wall which are 150 mm (5.9 in) in diameter.

The blowers take moist air from above the residue quench channel to which, in winter, warm air taken from the top of the furnace room is supplied.

Boiler Water Treatment

City water is used for boiler water makeup. Hydrazine and trisodium phosphate are added. The makeup is required by blowdown of 9 to 10 tonnes/day (2,378 to 2,642 gals/day) from each boiler plus use of a total of 15 to 20 m^3/day (9,511 to 10,040 gals/day) for soot blowing. Every 8 to 12 weeks, the boilers are emptied for maintenance and cleaning and then refilled. Since the energy of the steam is transferred at the plant to hot water for the district heating system, there are no problems with condensate return from outside the plant.

ENERGY UTILIZATION EQUIPMENT

Gothenburg has the largest hot water district heating system in Europe, most of it heated by oil-fired boilers. The longest pipeline is 20 km (12.3 mi) one way. The steam produced from refuse at the Savenas plant is used to heat water to 150 C (F) at 14,5 kg/m^2 (207 psia) (1.423 kPa). The temperature drop in the district system is 80 C (176 F) and the hot water flow rate is about 200 m^3/hr (881 gpm) in the summer and 700 m^3/hr (3083 gpm) in the winter.

Table 11-2 shows the monthly results.for 1976 on production and utilization of the energy from refuse as published in the GRAAB Annual Report. Figure 11-14 from the same report shows the monthly trends in heat recovery and utilization.

TABLE 11-2. ENERGY PRODUCED BY SÄVENÄS PLANT IN 1976[2]
(Courtesy GRAAB)

	Refuse Quantity	Heat Recovered[1]	Heat Utilized	Proportion of Heat Utilized
	Tonnes	Gcal	Gcal	Percentage
January	20,500	28,300	23,300	97
February	18,900	27,700	23,900	99
March	21,900	33,400	27,600	97
April	21,600	31,800	22,100	82
May	21,400	31,900	14,700	54
June	21,000	26,400	9,900	44
July	17,000	26,400	7,900	35
August	19,800	25,900	13,700	62
September	22,500	31,900	19,000	70
October	21,600	29,100	19,600	79
November	22,200	28,900	22,600	92
December	21,100	33,400	28,500	98
Total	249,500	355,100	232,800	77
Electrical Equivalent		(413,000 MWh)	(271,000 MWh)	

(1) Includes about 15 percent as internally used heat. (1 Gcal = 1.163 MWh)

(2) Utilities consumed:

- Industrial Water - 0.64 m^3/tonne waste
- City Water - 0.26 m^3/tonne waste
- Electricity - 13,300 MWh; 53 KWh/tonne waste
- Residue Disposed - 73,000 tonne
- Residue Disposed - 29.3 percent of weight of waste

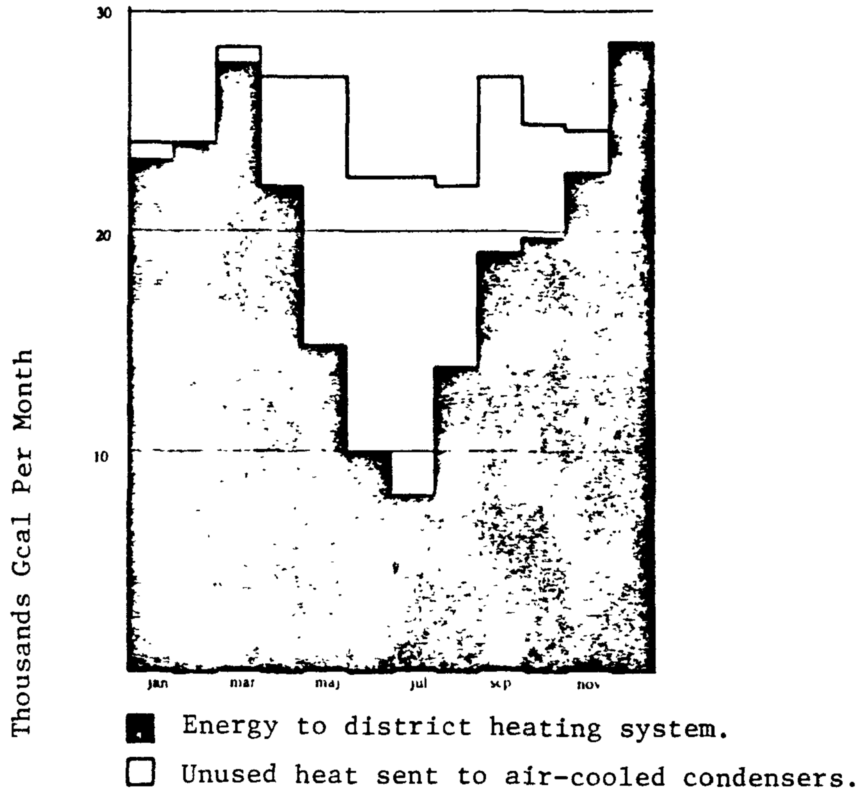


FIGURE 11-14. MONTHLY TREND FOR 1976 OF HEAT PRODUCTION AND UTILIZATION. (Courtesy GRAAB)

POLLUTION CONTROL EQUIPMENT

The three electrostatic precipitators were built by Svenska Flaktfabriken for a flow rate of 100,000 Nm^3/hr (58,850 scfm). Flow model tests were not used in the design. Average velocity was 1.15 m/sec (3.8 fps). Particle residence time was 4.8 sec. There are two fields.

When the precipitators were tested in 1973, the guaranteed emission limit of 150 mg/Nm^3 (0.041 gr/scf) corrected to 10 percent CO_2 was exceeded. Accordingly, the manufacturer provided an additional smaller precipitator besides the three others to which a portion of the gas is bypassed. The result is lower velocity, longer residence time, and the combination now meets the 150 mg/Nm^3 design limit. For this size of plant, the allowable legal limit is 180 mg/Nm^3 at 10% CO_2 and dry gas. Regulations require that the precipitators be tested twice per year.

Some corrosion has been found near the top of the last field caused by excessive temperatures. Attempts are made to hold it to 250 C (482 F), but at times it reaches 300 C (572 F). Hopefully the planned installation of additional heat absorbing surface in the second pass of the boilers will help to reduce the precipitator temperature (These installations are ordered for units and operation start is expected in November 1978).

Chimney

Figure 11-15 shows the unusual square concrete chimney 120 m (394 ft) tall, which contains three mineral-wool insulated corten-steel flues, 1.6 m (5.25 ft) in diameter. There is room for another flue if the fourth boiler is added in the space provided in the plant. The chimney also contains a two-passenger industrial elevator which facilitates the testing or flue gas and changing of aircraft warning lights from platforms located every 20 m (65 ft) within the chimney. Slight corrosion has been observed in welds at the top.

Figure 11-16 shows a view of a nearby residential area from the top of the chimney. The interior of the top of one flue is visible at the left. A very thin deposit of fine, white ash coats the interior.

FIGURE 11-15. UNUSUAL SQUARE CHIMNEY (Battelle Photograph)

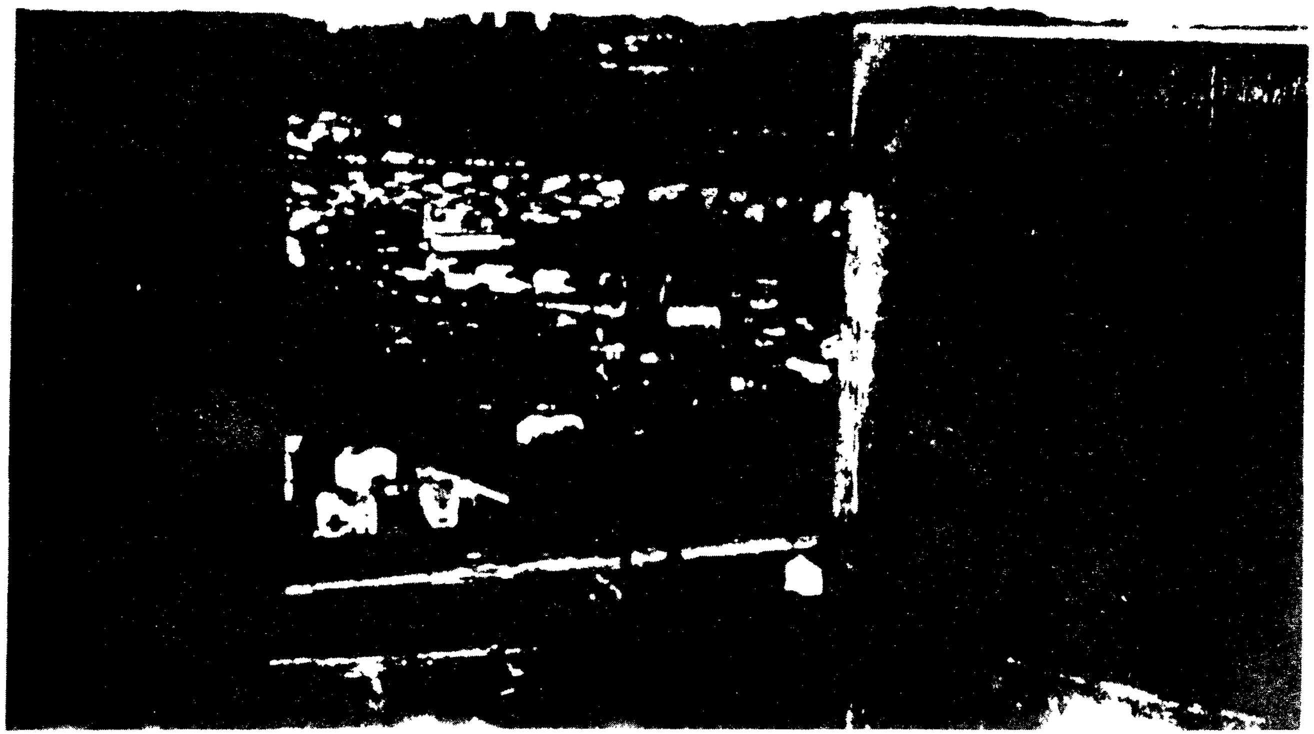


FIGURE 11-16. NEIGHBORHOOD OF SAVENAS PLANT VIEWED FROM TOP OF CHIMNEY LOOKING BETWEEN TWO CHIMNEY FLUES (Battelle Photograph)

Wastewater Discharge

There is no wastewater discharge from the plant except sanitary waste water. Process water from the quench tank and slaggunker is collected in a pump pit and recirculated to the hot quench tank.

Noise

To suppress the noise of the large fans which supply air to the air-cooled condensers, they are enclosed in perforated louvered walls. This has reduced the noise level 100 m (328 ft) from the plant from 58 to 50 dB. Noise regulations now for new plants require 45 dB(A) in the day and 35 at night.

Residue Disposal

The new Tagene landfill which receives the residue has a clay base from which drainage is collected and piped to the city wastewater treatment plant. When the system was planned, there were tentative plans for metal recovery from the residue. The planned metal recovery has not been implemented to date.

POLLUTION CONTROL ASSESSMENT

The clean appearance of the plant and the data indicate that it is achieving a high degree of environmental acceptability in its operations. By achieving its design particle emission limit of 150 mg/Nm^3, (0.066 gr/scf) it is well within the 180 mg legally allowed for furnaces burning over 15 tonnes/hr (16.5 tons/hr). Smaller plants are allowed up to 250 mg/Nm^3 (0.109 gr/scf).

A new regulation of the national environmental control agency, Statens Naturvord Verket (SNV) is that if a plant is emitting more than 40 mg/Nm^3 of total acid, equivalent, studies must be undertaken to seek feasible means for control. The acid equivalent emissions from Savenas were not stated.

EQUIPMENT PERFORMANCE ASSESSMENT

The system is achieving its goals of useful energy recovery while disposing of the industrial and community solid wastes from 670,000 inhabitants in nine communities. Various equipment problems have been encountered as already described and as solutions have been found, overall performance is improving. Final costs per unit of waste handled have increased due to inflation and equipment modification.

Table 11-3 summarizes the plant input and output in 1976. The refuse monthly input data are a few percent lower than those shown in the previous Table 11-2, apparently because the plant receipts did not include some bulky noncombustibles that entered the system but were diverted from the plant because they had no fuel value.

The total length of time that each unit operated for the year corresponds to the following availabilities of total houres per year on 7-day week plant operation:

Unit 1	76 percent
Unit 2	84 percent
Unit 3	72 percent

These are typical availabilities for this type of plant.

The heat utilized--235,869 Gcal--amounts to 0.9725 Gcal/tonne of refuse (3.508 M Btu/ton). Assuming the current estimated average heat value of 2,350 Kcal/kg, this represents a final annual use of 41.4 percent of the potentially available energy in the refuse. Assuming a boiler-furnace efficiency of 70 percent, this corresponds to an effective use of 59 percent of the energy generated as steam. As seen in Figure 11-14, introduced earlier, a significant block of the energy liberated must be dissipated in the air-cooled condensers in the 4 months May through August because little district heating is needed then.

TABLE 11-3. 1976 OPERATING RESULTS FOR SAVENAS PLANT (Courtesy of Graab)

	Refuse Burned Tonnes				Time of Operation Hours			Steam Production Tonnes				Treated Boiler Feedwater	Total Feedwater	Industrial Water Used	Energy Recovered	Power Consumption
	Unit 1	Unit 2	Unit 3	Total	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3	Total	m^3	m^3	m^3	Gcal	kWh x 10
January	8,639	7,694	2,451	18,784	698	627	231	29,908	23,709	7,827	61,444	2,063	4,981	11,093	23,259	1,112
February	3,489	7,534	8,116	19,139	340	696	693	12,159	22,264	25,832	60,255	2,052	3,973	13,641	23,876	1,065
March	6,698	7,234	8,748	22,680	564	678	740	22,365	21,784	28,419	72,568	2,365	5,228	13,406	27,619	1,226
April	8,280	5,967	6,832	21,079	718	467	642	27,429	18,194	23,450	69,073	2,214	4,665	15,104	22,143	1,140
May	4,300	9,236	8,374	21,910	342	713	689	13,900	27,852	27,690	69,442	2,354	4,583	13,915	15,313	1,176
June	8,294	8,081	1,847	18,222	692	708	200	27,003	24,699	5,798	57,500	2,388	5,352	15,089	10,860	1,033
July	3,117	7,848	7,422	18,387	252	639	636	10,180	24,308	22,872	57,360	2,354	10,304	11,451	8,834	1,067
August	7,268	6,328	3,859	17,455	723	634	430	23,974	19,991	12,347	56,312	2,448	5,367	15,500	14,006	1,029
September	3,763	9,487	8,334	21,584	322	719	704	12,684	29,709	26,882	69,275	2,251	4,536	14,367	19,145	1,118
October	8,172	9,608	2,212	19,992	725	744	193	27,494	29,003	6,792	63,289	1,808	3,429	11,334	19,578	1,057
November	7,496	6,983	6,121	20,600	667	624	487	24,034	20,298	18,471	62,803	2,619	6,910	9,150	22,711	1,095
December	7,331	6,818	8,555	22,704	643	511	706	24,009	21,722	26,943	72,674	2,403	4,823	14,741	28,525	1,178
Total	76,847	92,818	72,871	242,536	6,686	7,360	6,351	255,139	283,513	233,323	771,995	27,319	64,151	158,791	235,869	13,296

Table 11-4 summarizes the plant performance for the 3 years, 1974-1976. The major changes to the water-tube walls and secondary air system in 1975 caused a loss of operation, particularly with Unit 2. All of the units increased operation in 1976, particularly Unit 2, which is a hopeful sign that many of the early problems have been solved.

TABLE 11-4. SÄVENÄS ANNUAL RESULTS 1974-1976

Furnace start-up: 1972 Capacity: t/24 h 3 x 300		1974	1975	1976
Operating Personnel				
Day Personnel		22	28	
Shift Personnel		20	20	
Total		42	48	
Refuse Fired	tonne	214,885	187,319 (1)	242,536
Residue	tonne	66,133	56,165	
Operating Hours				
Furnace 1	h	6,242	5,484 (2)	6,686
Furnace 2	h	5,700	4,751	7,360
Furnace 3	h	5,852	6,035	6,351
Total		17,794	16,270	20,397
Availability	percent	67	62	77
Steam Production	tonne	663,906	586,668	771,995
Steam Production/t Refuse	tonne	3.09	3.13	3.18
Heat Supply	Gcal	178,922	184,068	235,869
Power Consumption x 1000	kWh	10,248	10,537	13,296
Power Consumption/t Refuse	kWh/t	47.69	56.25	54.82
Water Consumption				
Total Water Consumption	m3	217,660	173,963	186,110
Industrial Water	m3	185,091	141,698	158,791
Water Consumption/t Refuse	m3/t	1.01	0.93	0.77
Boiler Feed Water	m3	32,569	32,265	27,319

(1) Total stop about 15 days.

(2) Boiler revision and repair.

PERSONNEL AND MANAGEMENT

Mr. Bengt Rundqwist, the Plant Director, reports to the Board of GRAAB. He prepares the agenda for the Board's working committee which meets about twice per month. His total staff in 1975 is 48. There are five shifts, four workers per shift: foreman, crane operator, furnace man, and control room operator. Formerly, the work-week for shift workers was 40 hours. Now it is 32.3 hours because it is demanding work and requires six shifts. The maintenance staff works a 40-hour week.

The salary of the shift foreman is 5,600 to 5,800 skr/mo ($1,120 to $1,160 @ 5 skr/$), including social benefits. The crane operator earns 4,800 skr/mo. Workers receive free working clothes, special shoes once per year, subsidized cafeteria service and coffee, and use of the sports club equipment, maintenance of which costs 3,000 to 4,000 skr/yr. Free classes and training are provided. The plant participates in a cooperative education program.

Many workers are recruited from the navy and merchant marine and nearby refineries. All workers have had 9 years normal schooling. A boiler operator must have 1 year of special schooling plus 40 weeks of practice.

The workers' union has the right to review all questions that affect workers before they go to the Board for consideration. If the planned-for eventual fourth unit is considered, it must have union approval.

Figure 11-17 shows the spacious control room with comfortable rest center at rear left.

FIGURE 11-17. CONTROL ROOM AT SAVENAS PLANT. THE FOLIAGE PLANTS AT LEFT DECORATE THE COFFEE AND REST AREA. (Battelle Photograph)

ENERGY MARKETING*

The entire energy output is hot water which is supplied to the large district heating system which serves about 200,000 flats and a nearby new hospital. The bulk of the 660 Gcal/h (2,620 G Btu/h) (2,763 GJ/h) produced for the system comes from the exhaust of back-pressure turbo-generators powered by oil-fired boilers.

In winter months, as seen earlier in Figure 11-14, the Savenas plant sends about 23,000 Gcal/mo to the system, an average of about 32 Gcal/h (127 G Btu/h) (134 GJ/h).

The Savenas plant wholesales the energy to the district heating system at about 40 skr/Gcal ($2.02/10^6$ Btu) (9.55 skr/GJ) (0.0344 skr/kw-hr thermal) @ 5 skr/$. The retail price of this energy delivered to the customers is about 60 skr/Gcal ($3.03/10^6$ Btu).

Ten years ago in 1967, the system purchased 1 percent sulfur, No. 5 oil for 57 skr/m^3, about 63.3 skr/tonne ($.04/gal). In 1976, it had increased to 450 skr/m^3 or 500 skr/tonne ($.34/gal @ 5 skr/$).

The total heating system serves 200,000 flats each of which averages 100 m^2 (1,076 ft^2) in living areas. The monthly bill is calculated from the following:

$$\text{Cost of heat} = 0.129 \times W \times B + 18{,}000\ E \times \frac{k}{200}$$

in which

W = energy, Gcal

B = oil cost, skr/m^3

E = capacity of the individual heat exchanger, Gcal/hr

k = cost of living index which was 400 in late 1977.

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* To repeat, this report uses 1975 to 1977 expense and revenue figures @ 5 skr/$.

For a 100 m^2 flat, the value of E is about 0.085, which is based on a heat load of 0.085 Mcal/h-m^2 (31.3 Btu/h-ft^2). Thus, the maximum monthly cost to heat a flat if the heat operated at full capacity all month would be 3,414 skr ($682 @ 5 skr/$). Even operated at half capacity this would be $341/mo.

In arranging to serve a suburb city (BERGSJO), 1 and 2 km (0.6 to 1.2 mi) away, the Savenas plant paid one third of the cost, 3.5×10^6 Skr skr ($700,000), for the pipeline that had to go through hilly terrain.

ECONOMICS

Construction of the Savenas plant, which was completed in 1971, cost about 98 million skr ($24.5 million @ 4 skr/$) not including the cost of land which is leased for 105,000 skr/year. The rest of the waste handling system, including the transfer stations, the new Tagene landfill, and the 30 transfer trucks, cost an additional 22 million skr ($5.5 million @ 4 skr/$).

In 1976, the approximate operating costs including depreciation are shown in Table 11-5.

For the 1976 input of 242,536 tonnes, this results in an operation and maintenance cost, including depreciation, of 84.5 skr/tonne ($16.90/ton). About one fourth of this, $4.64, is for interest and $2.14 is for depreciation.

An added one-time cost in 1976 was 3.5 million skr paid to the district heating system for a one-third share of the cost of a 1.5 km heating line to Bergsjo.

Revenues

The operating budget (expected results) for 1977 is shown in Table 11-6.

TABLE L-24. OPERATING BUDGET FOR 1977 AT GOTHENBURG COST ALLOCATIONS (Estimated for a Waste Quantity of 250,000 ton)

	Annual Cost 1000 skr		Cost per tonne, skr/tonne		
1. Capital costs	15,171	(18,721)		60.70	(74.9)
2. Administration	2,119			8.45	
3. Incinerator, operating cost	6,558		26.25		
4. Incinerator, repair and maint. cost	5,888		23.55	49.80	
5. Transfer stations, operating cost	1,411		5.65		
6. Transfer stations, repair and maint.cost	710		2.85	8.50	
7. Landfill, operating cost	679		2.70		
8. Landfill, repair and maint. cost	232		0.95	3.65	
9. Refuse hauling	2,208			8.85	
10. Residue hauling	685			2.75	
Total Costs	35,661	(39,211)		142.70	(156.9)
11. Income from district heating	8,161			32.70	
12. Income from tipping fee	27,500	(31,050)		110.00	(124.2)

Note: The data are from the annual report for 1976 "Åresredovisning" which served as the basis for the 1977 budget.

Conversion example: $\frac{2{,}100{,}000 \text{ S.Kr.}}{1 \text{ Year}} \quad \frac{1 \text{ U.S. \$}}{4.127 \text{ S.Kr.}} \quad \frac{1 \text{ Year}}{242{,}536 \text{ Tonnes}} \quad \frac{1 \text{ Tonne}}{1.1 \text{ Ton}} = \$1.91/\text{Ton}$

i.e., Multiply all S.Kr. numbers by .0000009082316

FINANCE

The cost of the system in 1972 was about 120 million skr ($48 million @ 4 skr/$). In 1969, the communities represented in GRAAB raised 4.5 million skr ($1.125 million @ 4 skr/$). On the basis of this commitment, GRAAB borrowed 90 million skr for 20 years from a major pension fund at 7.3 percent interest. After 10 years, this interest can be adjusted depending on interest trends at that time. Communities which borrow such large sums must first have approval of the Swedish government.

Because the final cost of the system nearly doubled over the early estimates, additional money was borrowed on similar terms in order to complete construction.

The financial condition of GRAAB is published in detail in the Annual Report.

REFERENCES

(1) Feindler, Klaus S., "Refuse Power Plant Technology - A State of the Art Review", Paper presented in New York, December 16, 1976, to the Energy Bureau, Inc.

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

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

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CONVERSION FACTORS

English Units Versus SI (and Metric) Units

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

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

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

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

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

(a) Exchange Rate at end of period.

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

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

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