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European Refuse Fired Energy Systems

Evaluation of Design Practices

Volume 6

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and State Solid Waste Management Agencies*

EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

Horsens Refuse Fired Heating and Sludge Drying Plant
Horsens, Denmark

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Volume 6

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

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DRAFT TRIP REPORT

to

HORSENS REFUSE-FIRED HEATING AND SLUDGE DRYING PLANT, HORSENS, DENMARK

on the contract

EVALUATION OF EUROPEAN REFUSE-FIRED
STEAM GENERATOR DESIGN PRACTICES

September 28-30, 1977

to

U.S. ENVIRONMENTAL PROTECTION AGENCY

March 9, 1978

EPA Contract No. 68-01-4376
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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

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

APPENDIX A

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(Continued)

LIST OF PERSONS CONTACTED

Erling Petersen	City Director of Solid and Water Waste Management
Finn Larsen	Horsens Plant Manager
Harry Arnum	City Engineer, Horsens
Holger Sorensen	Burgomeister, City of Horsens
Nels Jurgen Herler	Engineer, Horsens Plant
Niels T. Holst	Chief Engineer, Bruun and Sorensen, Aarhus
Paul Sondergaard-Christensen	Engineer, Bruun and Sorensen, Aarhus
Allan Sorensen	Engineer, Bruun and Sorensen, Aarhus

The authors are very pleased to gratefully acknowledge the very kind and competent assistance given to us by the above individuals in assembling the information presented in this report.

SUMMARY

The small Horsens plant was originally built in 1973-1974 to dry sewage sludge only, using refuse from a population of 54,000 as fuel for heating a rotary drying kiln. But in 1977, it was converted to also generate hot water to feed into the city district heating system which is now heated primarily with oil. The dried sludge is not cofired with the refuse, but it could be. The recent conversion of the plant to supplement the district heating system makes it a unique type of refuse-to-energy plant.

Industrial waste constitutes a major portion of the total energy input, although, as with all Danish refuse systems, toxic and corrosive industrial chemical wastes are not burned locally but are sent to a single processing and incineration plant built by Von Roll at Nyborg.

A much larger plant was nearing completion at Aarhus embodying many of the principles evolved at Horsens. A brief description of that plant is included as Appendix A.

HORSENS STATISTICAL SUMMARY

Community Description:	
Area (square kilometers)	200
Population served	64,000
Key terrain feature	Hilly, coastal
Solid Waste Practices:	
Total waste generated (tonnes/year)	18,909
Waste generation rate (kg/person/day)	1.0
Lower heating value of waste (Kcal/kg)	2,800
Collection period (days/week)	5
Cost of collection (local currency/tonne)	--
Use of transfer and/or pretreatment	No
Distance from generation centroid to:	
Local landfill (meters)	1,000
Refuse-fired steam generator (meters)	300
Waste type input to system	Res., com., ind.
Cofiring of sewage sludge (yes or no)	No
Drying of sewage sludge (yes or no)	Yes
Development of the System:	
Date operation began (year)	1974
Plant Architecture:	
Material of exterior construction	Reinf. concrete
Stack height (meters)	60
Refuse-Fired Steam Generator Equipment:	
Mass burning	Yes
Waste conditions into feed chute:	
Moisture (percent)	--
Lower heating value (Kcal/kg)	2,800

Volume burned:	
Capacity per furnace (tonnes/day)	120
Number of furnaces constructed	1
Capacity per system (tonnes/day)	120
Actual per furnace	67
Number of furnaces normally operating	1
Actual per system (tonnes/day)	67
Use auxiliary reduction equipment (yes or no)	No
Pit capacity level full:	
(tonnes)	--
(m^3)	950
Crane capacity:	
(tonnes)	4.6
(m^3)	2.5
Feeder drive method	Hydraulic
Burning grate:	
Manufacturer	Bruun and Sorensen
Type	Sectional, rocking
Number of section	3
Length overall (m)	8.1
Width overall (m)	2
Primary air-max (Nm^3/hr)	30,000
Secondary air-overfire air-max (Nm^3/hr)	3,000
Furnace volume (m^3)	62
Furnace wall tube diameter (cm	None
Furnace heating surface (m^2)	None
Auxiliary fuel capability	No
Use of superheater	No
Boiler:	
Manufacturer	I/S Danstoker
Type	Vertical, firetube
Number of boiler passes	1
Heat production per boiler (Gcal/hr)	7
Total plant heat production (Gcal/hr)	7

Water temperature (°C)	110
Water pressure (kg/m^2)	--
Air Pollution Control Equipment:	
Mechanical cyclone collector	Cyclonic after combustor
Electrostatic precipitator	Yes .
Manufacturer	Svenska Flaktfabriken
Inlet loading of particulates (mg/Nm^3)	5,000
Exit - loading of particulates (mg/Nm^3)	180
Legislative requirement (mg/Nm^3)	180
Scrubber	None

Water:	
Total volume of waste water (liters/day)	--
Ash:	
Volume of ash (tonnes/day)	--
Volume of metal recovered (tonnes/day)	None

COMMUNITY DESCRIPTION

Horsens "town of horse power" is an industrial and seaport city of 54,000 population located at the head of the Horsens fjord on the island of Jutland. In 1970, its population was about 38,000, but as part of the consolidation of communities throughout Denmark, Horsens was at that time combined with five other communities.

Figure 13-1 is a map of the expanded Horsens community, which has a land area of about 200 km^2 (38.6 mi^2). To provide more fuel for its refuse-to-energy plant, Horsens is seeking agreements with surrounding communities. One town, Geved, population 10,000 located 10 km (6 mi) north of Horsens, has arranged to send all of its refuse to Horsens. On the map in Figure 13-1, Geved is near the top center.

The countryside is fairly hilly with many small towns closely spaced and connected by many roads. A north-south expressway, E3, passes through the western part of the city. Two of the neighboring towns use hearth-type incinerators, but in 1980, the law requires that these be shut down.

Figure 13-2 is an aerial view of the Horsens plant and, at the top, the new wastewater treatment plant. About one fourth of the weight of solid waste received at the plant is industrial waste. There are three plastics plants in town which produce waste of high heat value. Also, there are electronics plants and a telephone factory.

There are 15 communities around Horsens which comprise a region or "small state" called an AMT (similar to a city-county government). The trend of Danish communities to combine to form "AMT" regions is an old one which has been found good for making road decisions, regional planning, conducting refuse management studies, environmental review, and for exercising sanction power, which is the authority to stop practices that harm the environment. An AMT council is elected every 4 years. The plans for the Horsens refuse plant were approved by the Viej AMT council.

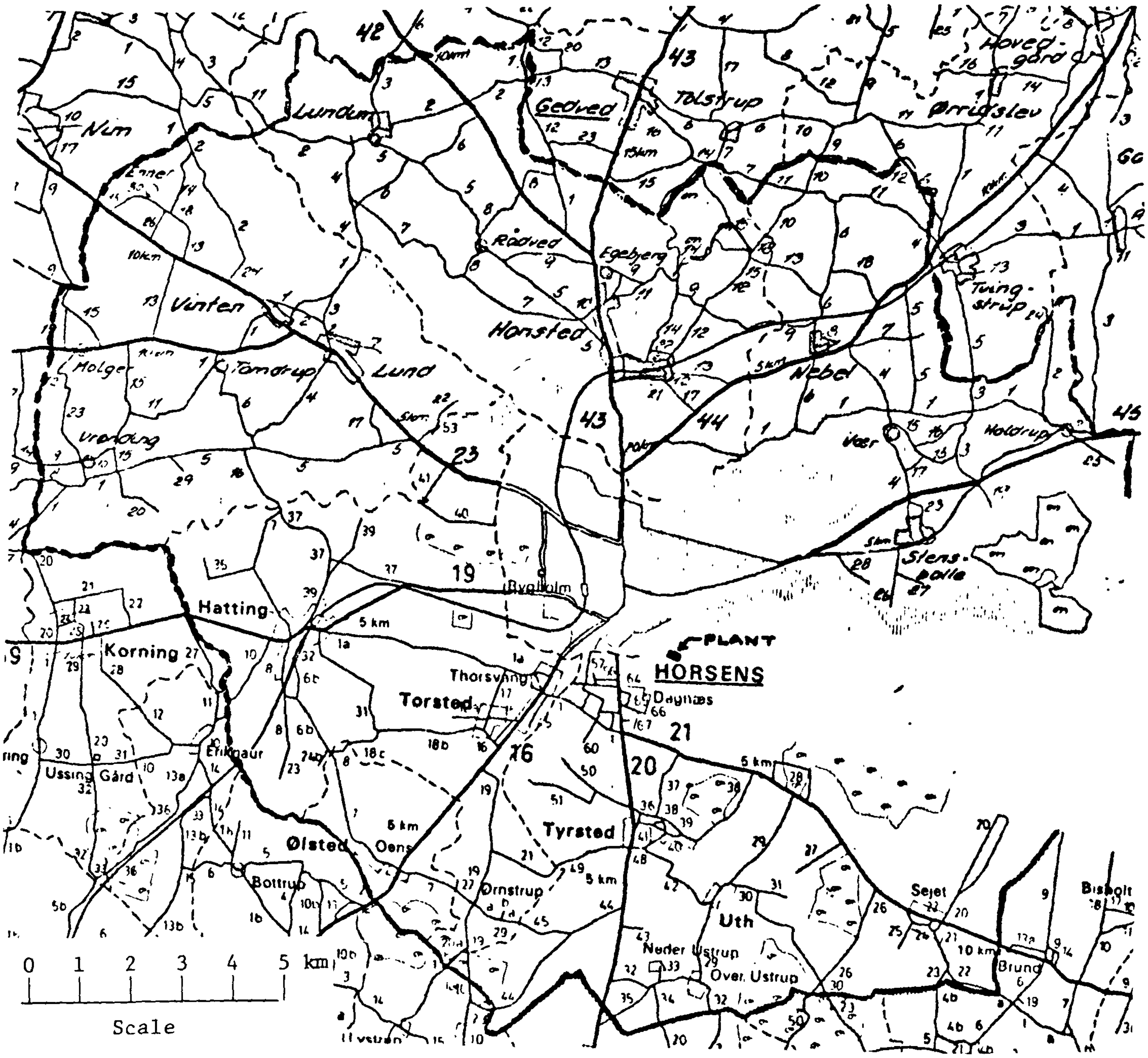


FIGURE 13-1. MAP OF AREA SERVED BY HORSENS REFUSE PLANT. THE COMBINED HORSENS COMMUNITY SERVED IS ENCLOSED IN THE HEAVY BROKEN LINE.

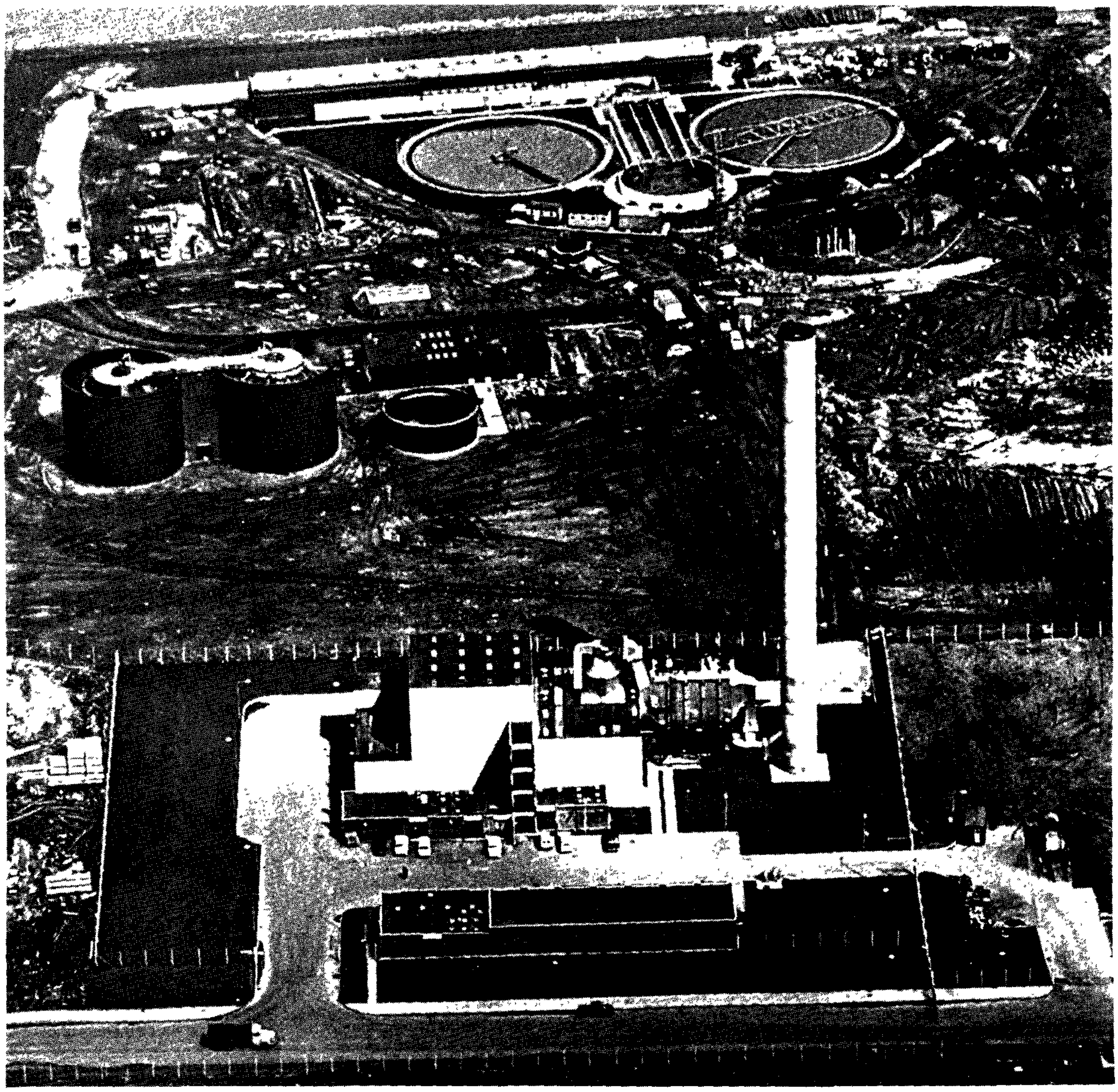


FIGURE 13-2. AERIAL VIEW OF HORSENS REFUSE-BURNING, SLUDGE-DRYING AND DISTRICT-HEATING PLANT. AT TOP IS THE NEW SEWAGE TREATMENT PLANT. AT FAR LOWER RIGHT IS A COLLECTION STATION FOR HAZARDOUS LIQUID WASTE WHICH IS SENT TO THE NATIONAL HAZARDOUS WASTE CENTER AT NYBORG (COURTESY OF BRUNN AND SORENSEN)

SOLID WASTE PRACTICES

Solid Waste Generation

It is estimated that at present about 16,900 tonnes/yr (18,590 tons/yr) are received at the plant, although only the trucks bringing industrial waste are actually weighed as they deliver. Of this total, about 4,300 tonnes (4,730 tons) are highly combustible industrial and commercial waste. The difference, 12,600 tonnes (13,860 tons), are of residential origin.

Table 13-1 shows the amounts of industrial waste received since the plant started in 1974.

Solid Waste Collection

The city operates five collection vehicles which bring a total of about 12,000 paper sacks of refuse to the plant during 5 days of each week, 8 hours per day. One suburban truck and about seven private truckers are also licensed to deliver. Their total weekly delivery is about 5,000 sacks. The paper sacks are provided by the city which buys about a million sacks per year from the F. L. Smith Co., manufacturer of cement sacks in Aalborg, Denmark.

The five city and seven private trucks are not weighed except occasionally to provide a record of a typical load. These checks indicate that the average loaded sack weighs about 15 kg (33 lb). On this basis, the 17,000 sacks per a 5-day week are the equivalent of 3,400 sacks per day, 51,000 kg/day (56.1 tons/day) (14,600 tonnes/yr) of household refuse.

The industrial waste input reached a total of 4,309 tonnes/yr in 1976, or an average of 16.6 tonnes/day (based on a 5-day week) (18.3 tons/day). Thus, the 5-day total estimated input is 67.6 tonnes/day (74.4 tons/day).

For the population served of approximately 64,000, including Ge' d, this total input rate represents an equivalent waste generation rate of about 295 kg/person/year (649 lb/person/year).

TABLE 13-1. QUARTERLY AND ANNUAL SUMMARY OF INDUSTRIAL WASTE RECEIVED AT THE HORSENS PLANT, TONNES PER QUARTER AND PER YEAR (COURTESY OF MR. FINN LARSEN OF THE CITY OF HORSENS)

	1974	1975	1976	1977
January-March	Start	932.4	983.7	731.5
April-June	762.3	884.8	1,018.8	681.0
July-September	743.9	875.2	1,018.8	1,050.2
October-December	955.4	1,041.6	1,287.6	--
TOTAL	2,461.6	3,734.0	4,308.9	--

Note: Reduced receipts in first two quarters of 1977 caused by plant shutdown for modification to add waste heat boiler.

Each collection worker is estimated to pick up and deliver 950 sacks per week. At 15 kg (33 lb) per sack, this amounts to 2,850 kg (6,270 lb) per worker per day.

Solid Waste Disposal

The burned residue is sent to a landfill adjacent to the plant where additional land is being built out into a shallow, dammed area of the fjord.

Industrial and Hazardous Waste Transfer Station

As part of this Energy and Environmental Park, the City of Horsens owns and operates an industrial and hazardous waste transfer station. All industrial and hazardous waste, by law, must be transferred to Nyborg, Denmark where four different waste processing lines treat the waste. This facility is taxpayer owned by the National Association of Municipalities. This is described in Appendix B.

DEVELOPMENT OF THE SYSTEM

In the early 1970's, the City Council of Horsens determined that the uncontrolled landfill then in use had to be replaced by an environmentally more acceptable method for disposal of solid wastes. Landfill fires and rats were objectionable. Accordingly, the city engineer visited 10 cities which had used various incineration systems to solve a similar problem.

At Horsens, composting had already been ruled out by an unsatisfactory experience with a modern composting system used from 1951 to 1965. From the start of its operation, assured markets for the product could not be maintained. Very little product was sold. In the last 5 years of operation, 1960-1965, none was sold.

In Denmark, well-managed landfills cost one half to one third as much to operate as incinerators, but in eastern Jutland, acceptable sites for new landfills are rare. Therefore, in 1972, Council decided to build an incineration plant. A letter defining the desired system was prepared by the Economic Development Committee of Council and was sent to various vendors inviting their interest. As a result, definite bids were received from three Danish companies: Bruun and Sorensen, Volund, and Elsinore. Bruun and Sorensen, whose main office is in Aarhus only 40 km (25 mi) away, was the low bidder. The plant details and final price were then negotiatted and the plant was built as a turnkey project.

In order to make use of some of the heat released by incineration, the plan included separate construction of a sewage treatment plant adjacent to the incinerator so that hot flue gas could be used to partially dry the digested sludge. Heat recovery for district heating was not added until 1977.

The decision in 1973 to build the plant was made solely by Council and no referendum was required. However, on January 1, 1977, a new Danish law became effective requiring that city plans must now be available for citizen scrutiny and comment. The final decision, however, remains with City Council, subject then to approval by the regional council.

Initially, it was hoped to locate the plant near one of the three existing privately owned district heating plants, but space was too confining and increased traffic there would have been difficult. The present ample site on a shallow, filled-in part of the Horsens Fjord is conveniently adjacent to the current landfill. Also adjacent is a chemical waste collection depot where such wastes are collected for shipment by barge to Denmark's nationally operated liquid and hazardous waste disposal plant at Nyborg, about 100 km (62 mi) southeast of Horsens.

As in many Danish communities, an important incentive toward clean alternatives to landfilling is the threat to groundwater quality from old, uncontrolled landfills. Also, since Denmark imports all of its energy, the recovery of energy from wastes has long been an important goal. The oil crisis of October, 1973 intensified the need for more waste-to-energy systems. At Horsens, additional refuse-fired heating plants are envisioned. Also, it is expected that in the future, to conserve energy, national legislation will require much more use of district heating, and some of this expansion will undoubtedly use refuse as fuel.

PLANT ARCHITECTURE

Figure 13-2, presented earlier shows an aerial view of the Horsens plant. At the top of the figure is the new sewage treatment plant which feeds digested sludge to the refuse plant for partial drying before disposal. The industrial and hazardous liquid waste collection is shown at the lower right. The tank car shown will be sent to Nyborg where Denmark's single hazardous waste processing center is located. All activities are under one management.

The main structure is built of reinforced concrete. The section containing offices, washroom, and control room are faced inside with very attractive glazed, reddish colored brick. Total building volume is 12,300 m^3 (142,352 ft^3), including 2,000 m^3 for the room containing the rotary kiln for sludge drying. The building is sized to accommodate a second furnace-boiler system.

Both plants are located on filled in land close to the center of the city where formerly there was a city landfill. The Horsens Fjord at that point is shallow and the filled land rests on 5 to 6 m (16.4 to 19.7 ft) deep layer of mud. Support of the refuse plant required 150 piles about 10 to 20 m (33 to 65 ft) deep.

REFUSE-FIRED HOT-WATER GENERATOR

As originally operated in 1974, this plant recovered no thermal energy as such but served only to dry sludge in a stream of hot flue gas from the refuse-burning furnace. However, in 1977, a hot water boiler was added to recover energy for the existing district heating system. The bulk of the energy for district heating is still supplied by three oil-burning plants 1.8 and 2.5 km (1.1 and 1.5 mi) away.

Heat Input

Few measurements have been made of the lower heat value of the refuse at Horsens, but it is believed to be fairly high because of the high combustible content of the wastes from the local electronics-oriented industries. Plant staff estimate that although the industrial component constitutes only one quarter of the refuse input, it provides about one half of the heat input. However, in designing the plant, Bruun and Sorensen assumed an averge heat value of only 2,000 Kcal/kg (3,600 Btu/lb) (8,372 kJ/kg), plus or minus 10 percent. That the actual average value is closer to 2,800 Kcal/kg plus or minus 10 percent is indicated by the opinion of plant staff that they need more residential refuse to dilute the "hot" industrial waste that tends to overheat their system. Spot samples of industrial waste only, analyzed in December, 1974, soon after the plant started, had lower heat values of 3,140 to 3,020 Kcal/kg (5,652 and 5,436 Btu/lb) [13,147 and 12,645 kJ/kg].

Weighing Operation

The 10-tonne scale is located inside the tipping hall adjacent to the pit. It is calibrated once a year by the manufacturer. Only the trucks delivering industrial waste are weighed and pay a fee. All others, unweighed, dump free. For the collection and disposal service, each household pays a tax. Occasionally, sacked residential waste are weighed for a week or so to obtain data to help estimate the residential input.

Refuse Storage and Retrieval

The control room operator also operates the crane and weighing platform which is adjacent to the pit. The operator has full view of all of this area through a large window overlooking the pit which is 9 m (30 ft) deep and has a total volume of 950 m^3 (33,525 ft^3). It can hold a 3-day supply. It is divided into two equal volumes, each 7.7 by 7.2 m (25 by 23.5 ft). In this way, the industrial and residential wastes can be separated. This enables the operator to mix them in appropriate proportions as he operates the crane to fill the single furnace hopper. The industrial pit is nearest the operator as it requires close scrutiny to enable the operator to control the mixture fired.

Bulky waste is not handled but is sent directly to the landfill nearby. However, plans have been made to install a shear at an estimated cost of 500,000 Dkr ($83,333 @ 6 Dkr/$). Some consideration is being given to use of a double screw device licensed by Norba and built by Volund for size reduction. One such installation at Horsholm is said to have provided good service for about 10 years.

The 4.6 tonne crane, operated semiautomatically, was made by Frederikssund Jernstoberi og Maskinfabrik of Frederikssund, Denmark. Figure 13-3 shows the 2.5 m^3 (88 ft^3) polyp-type grab made by Sven, now a part of Volund.

Pit fires are controlled by fixed nozzles located around the sides. When necessary, local firefighters use foam.

Furnace Hopper and Feeder

Figure 13-4 is a schematic diagram of the Horsens plant. There is only one furnace. The control room operator keeps the feed hopper full by means of the grab and crane. Once he has picked up a charge from the pit, the crane is programmed to position the loaded grab over the hopper. When it is in position, the operator actuates the grab to drop its charge into the hopper. The crane can feed a charge up to once every 4 minutes.

The top opening of the hopper is 4.2 by 4.8 m (13.8 by 15.7 ft), and it is 2.1 m high (6.8 ft). The refuse flows by gravity from the hopper

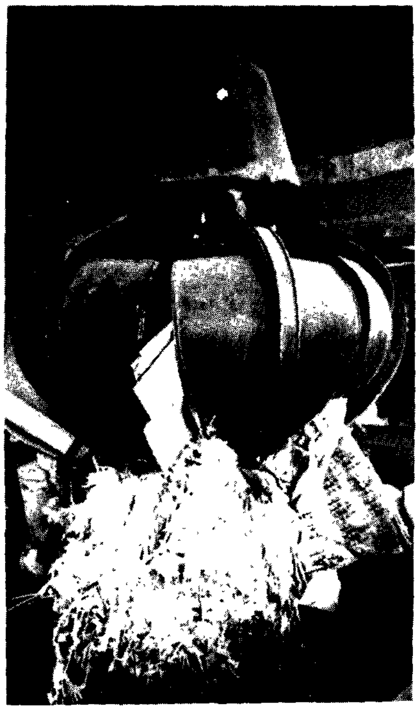
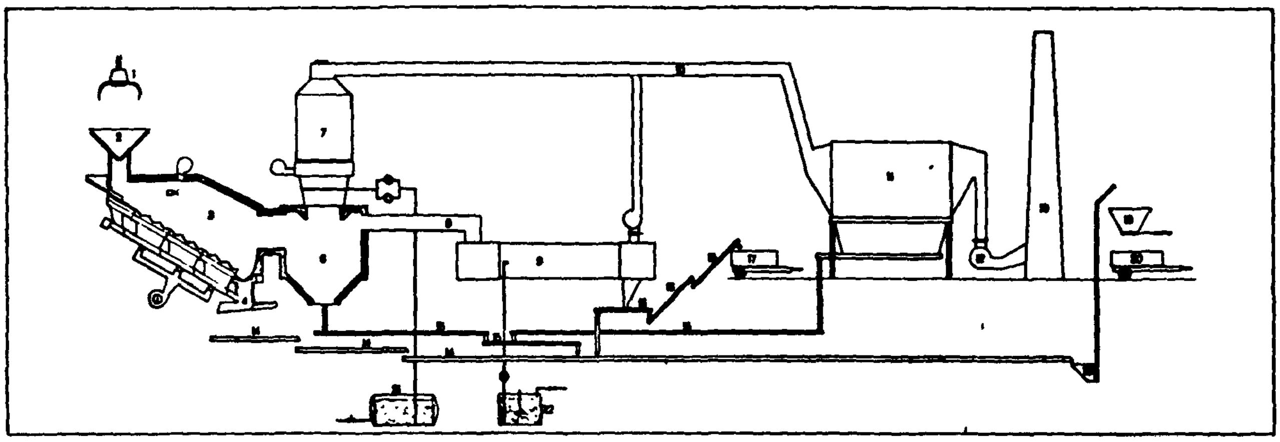


FIGURE 13-3. POLYP TYPE OF GRAB BUCKET USED AT HORSENS (COURTESY OF BRUUN AND SORENSEN)



1. GRAB
2. RECEPTION HOPPER
3. FURNACE
4. SLAG DISCHARGE
5. COMBUSTION AIR
6. AFTER-COMBUSTION CHAMBER
7. COOLING TOWER
8. COMBUSTION-GAS DUCT TO ROTARY DRYER
9. ROTARY DRYER
10. COMBUSTION-GAS DUCT FROM ROTARY DRYER AND COOLING TOWER.
11. ELECTROSTATIC PRECIPITATOR
12. EXHAUST FAN
13. CHIMNEY
14. SLAG VIBRATION CONVEYOR
15. SCREW CONVEYOR FOR FLY ASH
16. SCREW CONVEYOR FOR DRIED SLUDGE
17. CONTAINER FOR DRIED SLUDGE
18. SKIP HOIST FOR SLAG
19. SLAG BUNKER
20. SLAG CONTAINER
21. COOLING WATER
22. SLUDGE CONTAINER

FIGURE 13-4. ORIGINAL HORSENS SYSTEM FOR SLUDGE-DRYING ONLY. IN 1977, ITEM 7, THE SPRAY-TYPE GAS COOLING CHAMBER, WAS REPLACED BY A FIRETUBE BOILER (COURTESY OF BRUUN AND SORENSEN) into a refractory-lined feed chute 1.11 m high (3.6 ft) and 1 by 1.6 m (3.28by 5.2 ft) at the top, tapering out to 1.6 by 2 m (5.2 by 6.5 ft) at the bottom. Burnback can be arrested by a cast iron flap damper in the chute.

The poured refractory lining of the chute is 50 mm (2 in) thick, held in place by welded anchor rods.

At the bottom of the chute, the refuse is fed on to the sloping grate by a similarly sloping hydraulic feeder designed by Bruun and Sorensen and built by Monsund. The feed ram has a maximum stroke of 2.5 m (8.2 ft) and a capacity of 5 tonnes/ hour. Variable feed is provided by a timer which can be adjusted by the operator from 0 to 1 stroke/minute. The only problem with the feeder has been oil leakage.

Burning Grate

The hydraulic ram-type feeder feeds the refuse on to the 30 degree sloping sectional grate depicted in Figure 13-5. As shown in the lower three sketches of the figure, the grate sections oscillate rotationally in a coordinated rocking motion such that the burning refuse is induced to cascade downward along the sloping grate in a wave-like motion, thus slowly agitating the fuel bed so as to prevent compaction and consequent irregularity in air flow. The motion of each grate section is controlled by an adjustable timer.

The moving part of the grate is formed of three sections with six horizontal shafts in each section. The grate bars are fixed to the shafts. Figure 13-6 shows two typical grate bars which are 0.5 m (1.6 ft) long. The lower bar in the figure is 50 mm (2 in) wide. The upper one is a new design of bar which is 100 mm (4 in) wide. Recent experience at Horsens with a test section of the newer bar revealed that fine ash is less likely to adhere in the interstices between the bars; hence, less cleaning is required to maintain the gaps free for uniform air flow. Cleaning between the older bars required 2 man-days per week. With the new ones, cleaning is required every other week. Since the plant is shut down on weekends, there is no interruption in desired service. Cleaning is by means of a pneumatically driven chisel. Also, the new ones are less likely to break.

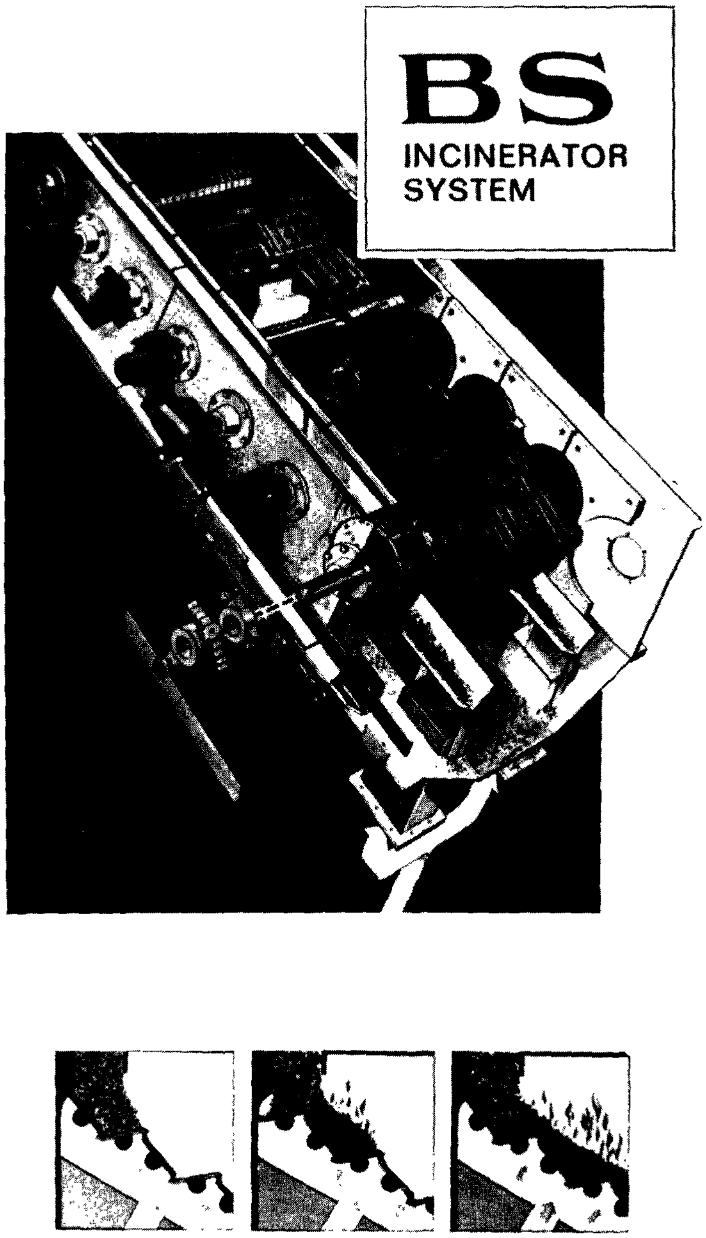


FIGURE 13-5. SKETCHES OF GRATE ACTION (COURTESY OF BRUUN AND SORENSEN)

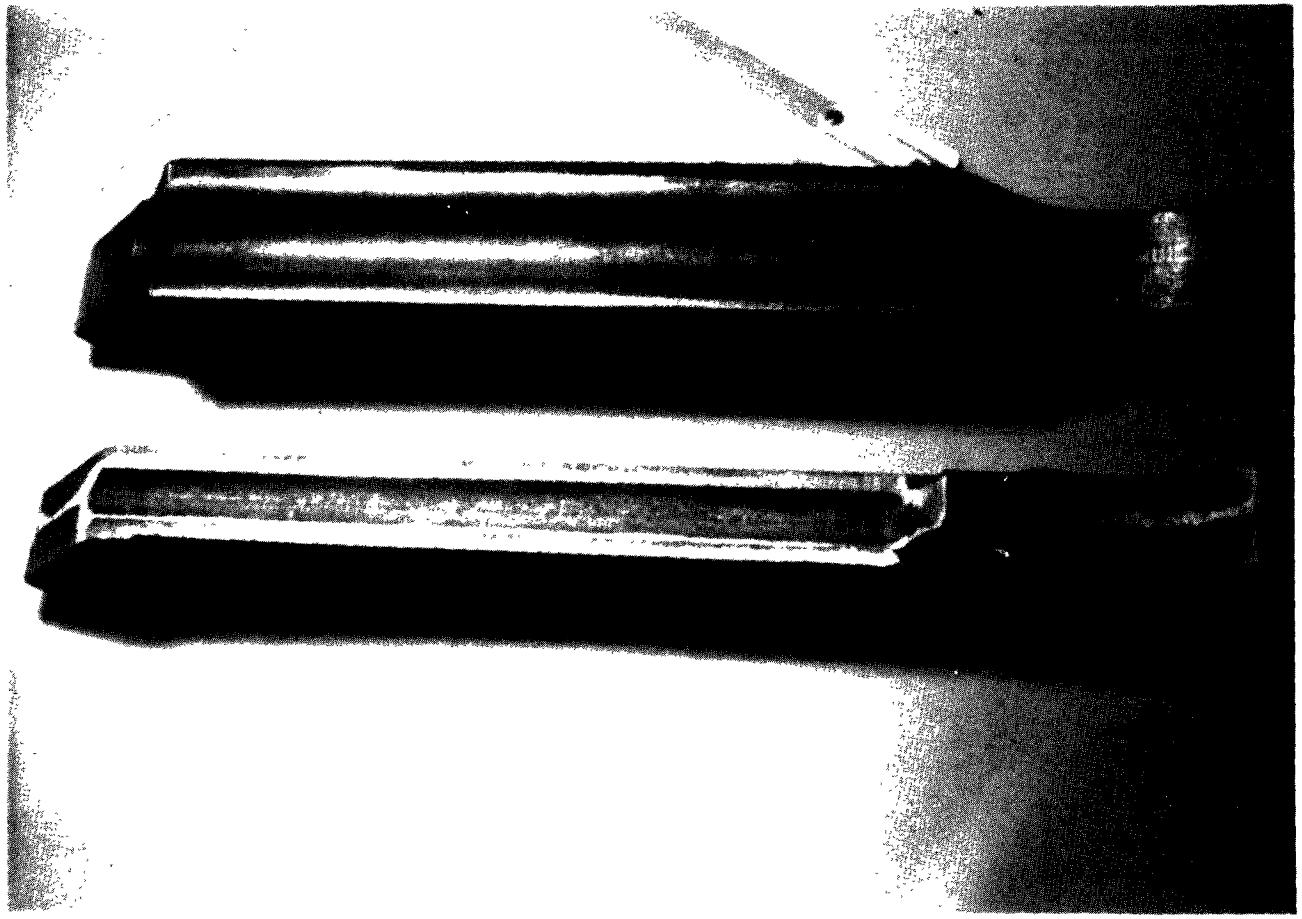


FIGURE 13-6. BRUUN AND SORENSEN CAST ALLOY GRATE BARS. THE OLDER BAR IS SHOWN BELOW. THE NEWER, WIDER BAR IS ABOVE (Battelle Photograph)

Replacement rate of the older bars has been at the rate of about 20/year. There were 720 of the older bars on 18 shafts. The new and old bars are cast by a Swedish affiliate of Bruun and Sorensen using an alloy of 23 percent chromium, 1.5 percent silicon, 0.2 percent nickel, and 0.25 percent molybdenum. They are guaranteed for 10,000 hours.

The grate is 2 m (6.5 ft) wide and 8.1 m (26.6 ft) long with a total area of 16.2 m^2 (174.3 ft^2). At the rated capacity of 5 tonnes/hr (5.5 tons/hr), this provides a burning rate of 308.6 $kg/m^2/hr$ (63.1 $lb/ft^2/hr$), a typical burning rate in many plants. As operated, burning 74 tonnes/ day (81.4 tons/day), the corresponding averge burning rate is only 190.3 $kg/m^2/hr$ (38.9 $lb/ft^2/hr$), a very modest rate. However, this is only an average, and since the plant does not operate at high rate at night, peak burning rates probably are much higher. Also, because of the relatively high heat value of the industrial waste received, relatively low burning rates are desired to avoid overheating the system.

The air pressure drop through the grate ranges from 158 to 165 mm (6.2 to 6.5 in) water.

The burned residue falls from the end of the grate into a sprayed quench chute which drops it then onto a series of vibrating conveyors shown in Figure 13-4.

Furnace Wall

The original plant was designed as a hot flue-gas generator for sludge drying; hence, the furnace wall is refractory without any heat recovery at the walls. The first meter (3.28 ft) of wall above the grate is formed of korund (45 percent silicon carbide) brick to discourage slag adhesion. Above that, the wall was originally firebrick but now castable or rammed refractory is used.

Originally, the furnace roof was a brick arch resting on steel supports, but because of overheating of the steel, it has been replaced by a poured flat roof of castable refractory supported externally. The new roof was designed by Hoganas using Hoganas "ES" refractory. It is stated to withstand 1,300 C (2,372 F). Its composition is SiO_2--36 percent; Al_2O_3--42 percent; and Fe_2O_3--6.1 percent.

The furnace volume is 62 m^3 (2,188 ft^3). At the rated 5 tonnes/hr of the expected refuse at only 2,000 Kcal/kg, the volume heat release rate would have been 161,290 Kcal/m^3/hr (18,100 Btu/ft^3/hr) (675 kJ/m^3/hr). However, the system design allows for burning in the furnace outlet channel and in the cyclonic-type after-combustion chamber, totaling an added volume of 51.4 m^3 (1,814 ft^3). Hence, the actual heat release rates are much lower than those just estimated. Nevertheless, because the actual refuse fired has a lower heat value considerably above the design value of 2,000 Kcal/kg, the furnace temperature reached in early operation reached 1,400 C (2,552 F) instead of the design value of 950 C (1,742 F). This overheated and warped the fire brick furnace wall which has now been replaced by castable refractory. In addition, furnace operation is now slowed to avoid overheating when much "hot" industrial waste must be burned.

Secondary air can be injected through ports in the roof as indicated earlier in Figure 13-4 , but these jets are seldom used except just enough to keep the air piping cool.

The refractory after-combustion chamber is 4.25 m (13.9 ft) inside diameter, 3 m (9.8 ft) high on top of a 2 m (6.6 ft) conical refractory hopper. Its intent is to provide gas mixing and burning time and to remove coarse fly ash from the hot gas stream. The CO_2 content of the gases leaving the chamber is in the range of 9 percent.

Figure 13-7 is an external view of the brightly painted steel shell of the after-combustion chamber with the cylindrical boiler located above it.

An early problem with the water spray cooling chamber, used before the boiler was installed in 1977, was that small amounts of water dropped from the spray chamber into the feed screw that removes coarse ash from the hopper below the combustion chamber. The wet ash sometimes hardened and stalled the screw. Replacement of the spray chamber by the boiler eliminated this problem.

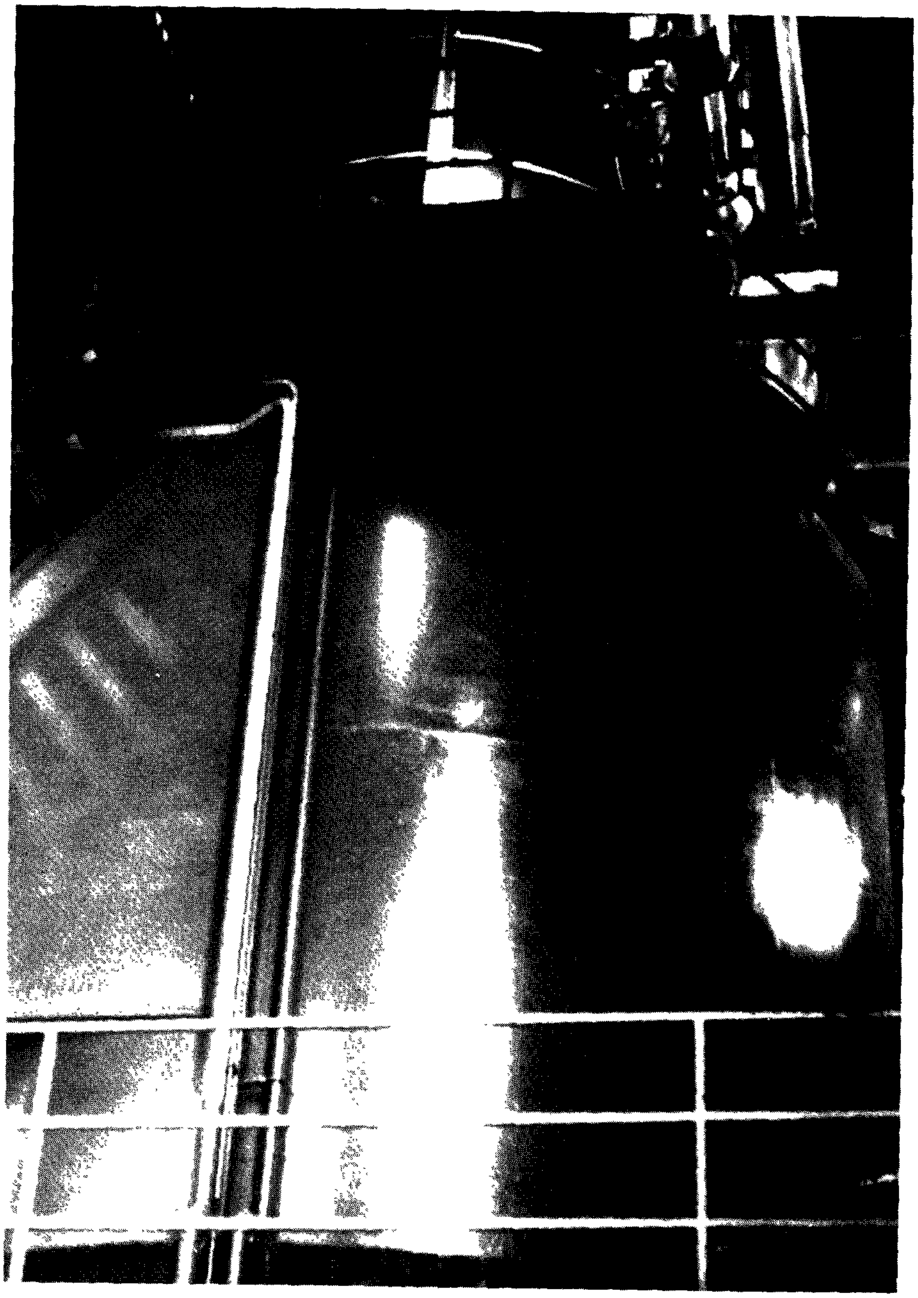


FIGURE 13-7. CIRCULAR AFTERBURNER WITH BOILER ON TOP AT HORSENS

Boiler

As shown earlier in Figure 13-4 , the original design had the hot, partly cleaned gases leave the after-combustion chamber at two points. From the top, they could flow vertically upward into a water-sprayed cooling chamber and, hence, to the electrostatic precipitator; or they could leave from the bottom hopper or horizontally through a refractory-lined duct to enter the rotary sludge dryer. However, the growing urgency throughout Denmark to conserve all available energy led in 1977 to replacement of the spray cooler by a waste heat boiler to supply hot water for the existing district heating system. This is a simple vertical firetube boiler built by the Danish Stoker and Heating Company. It contains 540 tubes, 57 mm in diameter (2.25 in) and 4.5 m (14.8 ft) long. Its capacity is 7 Gcal/hr (27,776 M Btu/hr) (29.308 GJ/hr). Heated water leaves the boiler at 110 C (230 F) and returns from the system at 80 to 90 C (176 to 184 F).

The top (exhaust) end of the boiler is accessible so that once every 2 weeks all of the 540 tubes can be cleaned of soft ash deposits by means of a powered rotating wire brush. This takes 6 to 7 hours every Monday morning at the same time that the air openings in the grates are being cleaned and the siftings are being removed from beneath the grate. The makeup water is treated by the main district heating plant.

When the spray cooling chamber operated, it had the capacity to cool all of the gases, 30,000 Nm^3/hr (17,655 scfm) from 900 C (1,652) to 300 C (572 F). There were 12 spray nozzles supplied by two pumps of 15 m^3/hr (66.0 gpm) at 33 bar (479 psia) capacity. At maximum cooling, the water consumption rate was 12 m^3/hr (52.8 gpm). Power capacity of each pump motor was 30 kW at 2,900 rpm. For only low-rate gas cooling, the chamber was provided with a fan to inject dilution air.

In summer, when some of the heat cannot be used, up to two thirds of the boiler capacity can be dissipated in air-cooled heat exchangers.

Primary Air

The primary air blower has a capacity of about 30,000 Nm^3/hr (17,655 scfm) at 200 mm water (7.9 in). It is supplied through one main damper to three under-grate zones, each controlled by a manually adjustable damper. These latter damper settings are seldom changed. The main flow damper can be controlled from the control room.

Secondary Air

About 10 percent of the primary air volume is available as secondary air at a pressure of 200 to 250 mm water (7.9 to 9.8 in). This air can be injected through ports in the furnace roof as shown in Figure 13-4. However, this air is seldom found necessary as sufficient burning time and gas mixing are usually provided by the cyclonic after-combustion chamber. Hence, usually only enough secondary air flows to cool the roof-ports and connected piping.

ENERGY UTILIZATION

Sludge Dryer

As already shown in Figure 13-2, the Horsens wastewater treatment plant serving a population of 38,000 was built adjacent to the refuse burning plant so that the difficult problem of sewage sludge disposal could be partially solved by partial drying of the sludge.

Figure 13-8 is another schematic view of the plant in which the rotary kiln type of dryer is emphasized

Typical analyses by the city laboratory of sludge pumped to the dryer are as follows:

	May 24, 1974	Sept. 5, 1977
pH	5.52	7.2
Dry Solids, %	13.3	6.5
Combustible, % of DS	66.7	46.7

The sludge is coagulated at the wastewater plant by means of a polyelectrolite and is then centrifuged before being pumped to the dryer.

The rotary kiln receives digested sludge from the sewage plant and reduces it from its nominal 5 percent dry solids content to approximately 70 percent dry solids. Hot flue gases and sludge are fed into the rotary kiln at the same end. The rotating part is carried on two rollers for axial control. A special scoop system ensures effective contact between flue gases and sludge. The rotary kiln is insulated with rockwool, covered with steel plate. The inlet end is lined with refractory brick.

The incoming sludge is fed by a monopump and the dried sludge is emptied by means of a spiral conveyor which leads the dried sludge to the clinker transport system, directly out of the building to a storage area.

There are then four possibilities for disposal of the dried sludge:

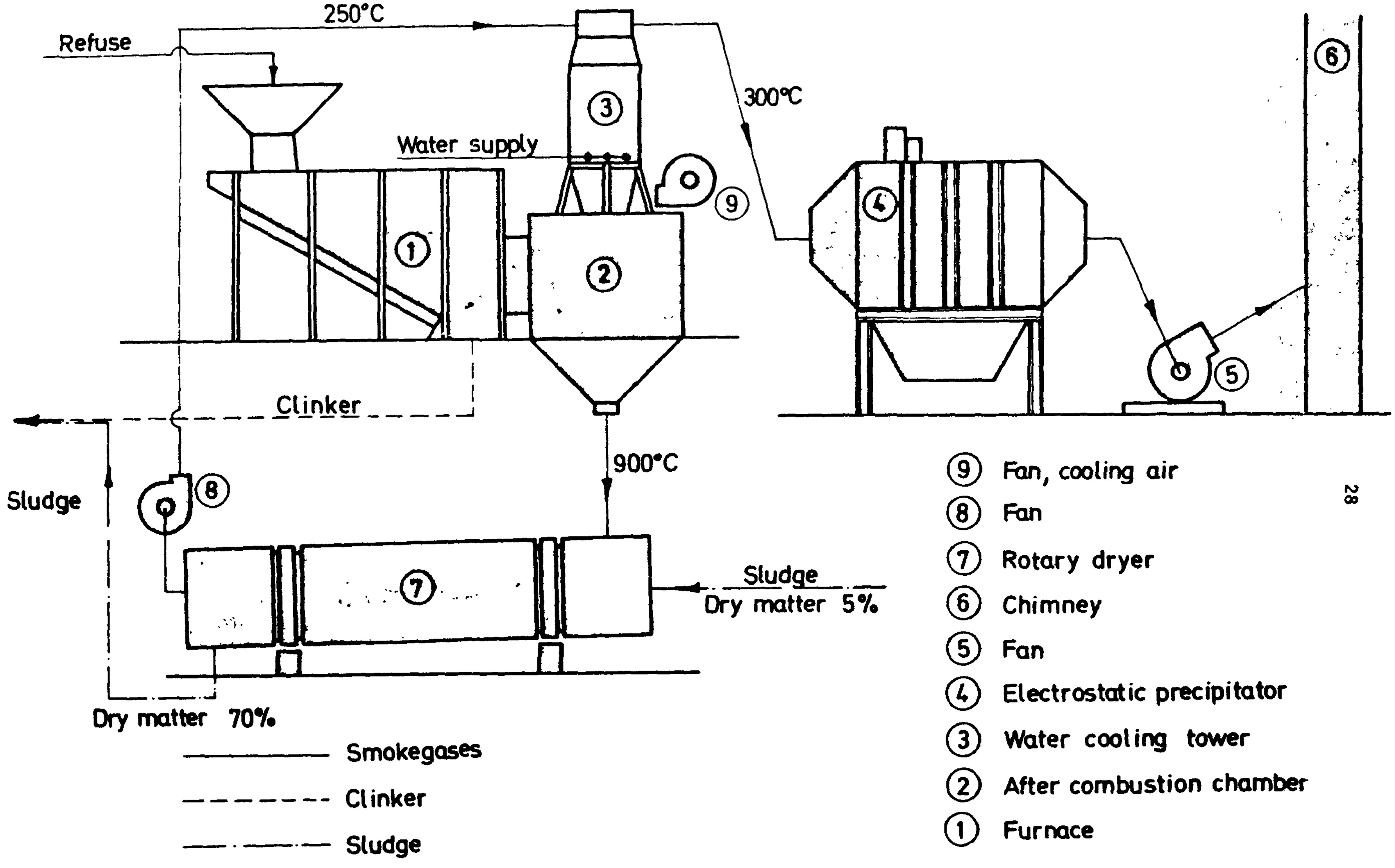


FIGURE 13-8. DIAGRAM OF HORSENS REFUSE-BURNING AND SLUDGE-DRYING PLANT (COURTESY OF BRUUN AND SORENSEN)

(1) Deposit with the clinker

(2) Burn in the furnace

(3) Utilize as fertilizer

(4) At present, it is deposited in the landfill. Later it may be spread in woodland to provide soil nutrients.

The kiln has the following specifications:

- Rotary dryer diameter: 2.5 m (8.2 ft)
- Length of dryer drum: 16 m (52.5 ft)
- Incoming sludge: Approx. 5 percent dry solids
- Outgoing matter: Approx. 70 percent dry solids
- Capacity: 5 m^3/hr (22 gpm) of wet sewage sludge
- Inlet flue gas temperature: Approx. 900 C (1,652 F)
- Outlet flue gas temperature: Approx. 225 C (437 F).

The sludge is reduced from approximately 5,000 kg/hr (11,000 lb/hr) to approximately 360 kg/hr (792 lb/hr) by going through the drying process. This represents an evaporation heat rate of about 2.70 Gcal/hr (10.2 M Btu/hr).

Some difficulty was encountered with odor from the kiln until high enough operating temperatures were assured on startup and shutdown.

District Heating System

Horsens is heated in part by a privately-operated hot water distribution system supplied from three oil-fired plants. In 1976, the operator of one of the systems requested supplemental hot water from the refuse plant which required the addition of the boiler, already described, and a 1.8 km (1.1 mi) transmission and return pipe which the city installed at a cost of about 2.5 x 10^6 Dkr ($416,700 @ 6 Dkr/$). With interest rates of 13 to 14 percent, it is estimated that the line will be paid for in 10 years. It will save about 2,500 tonnes (2,778 m^3) (17,475 barrels) of oil per year. At a cost of 600 Dkr/tonne of oil ($0.34/gal @ 6 Dkr/$), this represents a saving of 1,497,260 Dkr ($249,500)/yr.

Pipeline

The new hot-water pipeline utilizes a new pipe insulation developed by the organization of Danish communities which use district heating, Tjaerkam Pagniet of Nyborg. The conventional asphalt covering around the steel pipe is filled with porous insulating mineral granules. The protective covering can be repaired by enclosing any gap or break in the covering in a temporary shield, then filling the gap with the granules followed by hot asphalt. The assembly is believed to be very effective in insulating the pipe while preventing corrosion.

POLLUTION CONTROL EQUIPMENT

The partially cleaned gases that leave the cyclonic after-combustion chamber are cooled in the boiler and then pass to an electrostatic precipitator built by Svenska Flaktfabriken according to the general specifications as follows:

Flow rate:	36,000 Nm^3/hr (21,186 scfm)
Entering temperature:	
With spray cooler	300 C (572 F)
With boiler	220 C (428 F)
Dust load (at 10% CO_2):	
Entering	5 g/Nm^3 (2.194 gr/scf)
Leaving (max)	180 mg/Nm^3 (0.078 gr/scf)
Rectifier	50 kv, 800 ma
Precipitator volume	134.4 m^3 (4,730.9 ft^3)
Average flow area	21 m^2 (226 ft^2)
Velocity at stp	0.48 m/sec (1.6 fps)

The precipitator design was preceded by a flow model study which was deemed essential because of the complicated flow patterns produced by the combined flow of gas partially from the spray cooler and partially from the sludge dryer. In March, 1977, it was tested twice by the Horsens Levnedsmiddellaboratorium (Environmental Laboratory, formerly the Veterinarian and Food Lab), with emission results of 165 and 178 mg/Nm^3 corrected to 10 percent CO_2.

The outdoor precipitator is insulated with 100 mm (4 in) of rockwool encased in aluminum. Mechanical rapping is provided for both charging electrodes and collector plates. The collection hoppers are electrically heated to prevent condensation.

The fly ash is removed from the hoppers by a Redler conveyor. At first, the dry fly ash was added to the wet grate residue but that produced intolerable dust. Then the fly ash was mixed with the sludge leaving the drying kiln but a chemical reaction occurred. Now they are attempting to form clinker with the sludge in the kiln. If the metal content is not high, it might have some value as soil nutrient. Tests by the environmental laboratory have established that the fly ash is not harmful if ingested by animals.

The plant staff are well pleased with the precipitator performance as it has required minimal maintenance, although they observe that some degradation of collection efficiency has occurred in 4 years of operation.

Induced Draft Fan

The cleaned gases pass from the precipitator to the induced draft fan. The gas flow rate is modulated by a servo-controlled slide damper usually set to maintain a furnace vacuum of 10 to 15 mm water (0.4 to 0.6 in). If power to the fan motor fails, the control damper closes and a separate emergency damper opens to bypass the precipitator so as to protect it from excessively high-temperature gases.

Chimney

The induced draft fan discharges to a reinforced concrete chimney 60 m (197 ft) high, 4.5 m (14.8 ft) outside diameter, which is large enough to contain two steel flues, only one of which is now installed. The flue is insulated with rockwool.

Residue Disposal

The quenched residue is hauled to the adjacent landfill in a dammed area of the fjord.

A sample of the burned residue is analyzed daily by the city laboratory for combustible content by heating the dried residue in air to 600 C (1,112 F) for a long enough time that the combustible matter is oxidized. The following are some typical values of combustible content of the dry solids in percent:

Day Sampled	Date of Analysis (1977)		
	July 5	Aug. 10	Sept. 15
Monday	3.1	3.8	4.0
Tuesday	0.8	2.4	1.8
Wednesday	1.6	3.0	2.4
Thursday	2.0	5.6	3.5
Friday	3.2	2.9	2.0

These results indicate consistently good burnout. The plant specification called for a value of 5 percent combustible. A daily check on the trend of this number is a useful clue to the general performance of the furnace. As in all analyses of heterogeneous materials, the size of sample and mode of sampling can be critical in producing useful numbers. An occasional duplicate sample submitted for the same day would be helpful in assessing the data variability.

Operating Routine

The plant is down Saturday and Sunday for repairs. The other 5 days of operation is not at a steady pace but is on a varied schedule as follows:

Monday	6:00 a.m.	Startup every other Monday.
Monday	2:00 p.m.	On alternate Monday mornings the boiler and grate are cleaned which delays plant startup until 2:00 p.m. Operation is then continuous.
Tuesday		Operation around the clock.
Wednesday		Operation around the clock.
Thursday	10:00 p.m.	Shut down
Friday	6:00 a.m.	Start up
Friday	10:00 p.m.	Shut down.

Thus, of the total of 120 hours in a 5-day week, the plant operates 104 hours one week and 96 hours on the alternate weeks. After

Christmas and Easter, the load is such that 7-day, around the clock operation is required.

On weekend shutdowns, the induced draft fan is kept operating at a low rate to keep the system ventilated and dry. The refractory setting remains warm so that at the time of startup Monday morning the air flow entering the boiler is still about 40 C (104 F).

EQUIPMENT PERFORMANCE ASSESSMENT

Early problems resulting from higher than expected heat value of the refuse have been solved by some refractory revisions plus judicious furnace operation to avoid firing too much industrial refuse. In the 4 years of operation, only two truck loads of refuse have had to be sent to the landfill because the plant was down, except for the period in 1977 while the spray cooling chamber was being replaced by the waste heat boiler. This is especially notable when one considers that there is only one line, i.e., no redundancy.

POLLUTION CONTROL ASSESSMENT

The electrostatic precipitator has been very satisfactory. At first, some odor problem was encountered during startup and shutdown from incomplete burning of sewage sludge. This was corrected by assuring high enough temperatures in the rotary kiln before the sludge is injected.

Plant wastewaters are minor and are sent to the sewage plant. The dried sewage sludge is not burned because of concern for some of the metals content in the sludge becoming gas-borne and passing through the precipitator as fine dust. So far, it can be land spread satisfactorily.

The burned grate residue is satisfactorily disposed of in the enclosed area of the nearby fjord, which has been designated for land reclamation. Although there is much concern in all of Denmark that surface and groundwaters be protected from leachate from landfills, there is less concern here for the relatively small amount of leaching that might reach the saltwater of the Horsens Fjord. Also, extensive measurement of leachate from incinerated residue at Copenhagen has indicated that the metal oxides in the residue are not readily leached.

Some experimentation has been conducted by the Karl Kroyoer Laboratory in the possibilities of using the residue to make roofing tiles. The Kroyoer organization has previously developed the Destrogas process which may be applicable for pyrolysis of waste.

Noise

Danish regulations require that the noise level should not exceed 50 dbA at the fence of this type of plant. If in a residential area the limit is 45 dbA, day or night. There have been no problems in this waterfront area and no noise measurements have been made.

PERSONNEL AND MANAGEMENT

Erling Petersen is Director of Solid Waste Management and Wastewater Treatment for the Horsens area. Actual operation of both plants is managed by Finn Larsen whose office is in the town hall. The plant foreman is assisted by 9 shift workers who work 40 hours per week. The total staff at the refuse burning plant is 10.

ENERGY MARKETING

Since the hot water boiler and 1.8 km connecting pipe has been in operation only since May, 1977, there has not been enough time to accumulate much data on the new energy now being fed to one of the private district heating systems. However, some planning is being done regarding a possible 2.5 km (1.5 mi) connecting line to another plant six times as large as the first one. The cost of the line through part of the city would be 6 million Dkr ($1 million @ 6 Dkr/$). If that plan materializes, the plant would install its second boiler-furnace and much more refuse would be needed from neighboring communities.

The district heating plant is charged for the energy received at a rate calculated as 0.12 times the cost of heavy oil per tonne. When the refuse plant began supplying hot water to the system in May, 1977, oil cost 540 Dkr/tonne (30.7 cents/gal @ 6 Dkr/$). By September, 1977, the cost was 555 Dkr/tonne and a government tax of 80 Dkr/tonne brought the total to 635 Dkr/tonne (36.1 cents/gal). Therefore, in May, the charge for the heat delivered as heated water was 64 Dkr/Gcal and rose to 76.2 Dkr/Gcal ($3.20/M Btu @ 6 Dkr/$) in September, 1977 at the time of this visit. For comparison, a homeowner in Horsens buying distillate oil for his residence in September, 1977, paid 1,000 Dkr/tonne (85.3 Dkr/Gcal) (50.5 cents/gal) ($3.58/M Btu), including taxes (based on #2 oil with a specific gravity of 0.8 and a higher heat value of 141,000 Btu/gal).

ECONOMICS

Capital Cost

The plant was built in 1973-1974 as a turnkey project within the contract price which was composed of the following:

Equipment, installed	4,634,152 Dkr
Sprinkler system	85,315
Building including stack	3,639,800
Weighing scale	113,900
Rotary sludge dryer, installed	1,795,406
Garage	525,850
Miscellaneous: fence, landscape, roads	300,000
TOTAL CONTRACT COST	11,094,423 Dkr

There was no overrun. The building and stack are large enough to accommodate a second unit. This total cost results in a capacity cost for the 5 tonne/hr unit of 92,454 Dkr/daily tonne of capacity ($14,008/ton @ 6 Dkr/$). Compared to steam generators, this cost is very low.

However, in 1976-1977, the hot water boiler and transmission pipe were built for the following additional costs:

Boiler, installed	1,750,000 Dkr
Building modification	85,000
Sludge centrifuge, dryer changes	998,600
Building work	120,000
Circulation pump, tank, for district, installed	190,000
New pump building at district plant	724,200
Hot water transmission line, 1.8 km	1,700,000
Project supervision	221,000
Building changes at Dagnas heating plant	200,000
SUBTOTAL	5,988,800

Pipeline from satellite station to plant	740,000
Project management	96,200
Booster station	75,000
Extras, estimated	208,544
TOTAL COST	7,108,544

Adding this cost, 7,108,544 Dkr ($1,184,757), to the original plant cost brings the total waste-to-energy plant cost to 18,103,960 Dkr ($3,033,828). Based on a daily rated capacity of 120 tonnes/day, this is a capital cost rate of 151,691 Dkr/tonne-day ($22,984/ton-day). This cost is also comparatively low considering that the pipeline and other costs are included. A major factor in keeping the costs down is the use of a low-pressure, firetube water-heating boiler instead of a high-pressure, water-tube, steam boiler that would be required if power were to be generated.

Operating Costs

As explained under "Solid Waste Practices", five city trucks, one suburban truck, and six or seven licensed private trucks altogether deliver a total of approximately 17,000 paper sacks of residential refuse each week. The 10,000 sources are taxed 330 Dkr/yr ($55/yr), whether they have free city collection or if they pay for private collection. This fee does not include a value added tax of 15 percent (called the MOMS tax). When the plant was planned, this tax was 7.5 percent. As of October 3, 1977, it increased to 18 percent.

The tipping fee for the weighed industrial waste is 100 Dkr/tonne ($15.15/ton @ 6 Dkr/$). For the 4,308.9 tonnes delivered in 1976, this income totalled 430,890 Dkr ($71,815). This included the Danish value added tax. Without that tax, the income was 366,256 Dkr ($61,043).

Table 13-2 shows the projected operating budget for 1977 and 1978 which is evidently based on the experience of previous years. A major increase of expense for 1978 will be the added amortization cost of 1,904,300 Dkr ($317,383) for the new 1.8 km pipeline to the private district heating system. Partly offsetting that added cost will be the expected income from the sale of heat, 1,327,000 Dkr ($221,167).

TABLE 13-2. OPERATING BUDGET FOR HORSENS PLANT, 1977-1978 (COURTESY OF CITY OF HORSENS, MR FINN LARSEN)

	Budget 1977, Dkr	Budget 1978, Dkr
Expenses		
Administration	70,650	91,900
Staff salaries and benefits	732,600	971,650
Utilities and supplies	359,000	452,000
Property taxes, building repairs, maintenance	103,000	107,170
Residue hauling, truck maintenance, repair	14,000	14,730
Residue tipping costs	6,000	9,000
Tools	20,000	29,060
Equipment maintenance, repair, including outside labor	280,000	321,000
Administrative supplies, advertising	14,000	16,650
Chemical analysis	5,000	5,250
Amortization of principal, interest	786,200	1,904,300
Total Operating Expense	2,390,450	3,922,710
Income		
Fees from Geved community	130,000	150,000
Tipping fees (industrial waste)	368,000	410,000
Sludge dewatering, drying fee	246,000	442,000
Sale of heat	0	1,327,000
Total Income	744,000	2,329,000
Net Operating Cost	1,646,450	1,593,710
Number of households	16,700	17,115
Net cost per household	98.59	93.12

The net cost of operation per household served is expected to be 98 to 93 Dkr ($16.33 to $15.50). As totaled earlier, the households are each charged 330 Dkr/year not including the value added tax. Apparently the differnece 330 - 98 = 232 Dkr per household is partly placed in the reserves from which the original plant was financed, but this also cover the cost of collection, administration and revisions.

The annual inclome form the 17,000 sources is thus 5,610,000 Dkr (935,000) not inlcuding the value added tax. As estimated earlier, the weight of residential refuse is about 14,600 tonnes/yr (16,000 tons/yr). Thus, the individual household pays at the rate of abour 384 Dkr/tonne ($58/ton) for collection and disposal.

FINANCE

The initial plant cost in 1973 of 11,094,423 Dkr was self-financed out of bonds and reserves. In future financing, the plan is to build up the reserves again to the point that private borrowing can be avoided because the interest rates for such money is now 18 percent. If community reserves are used, the internal opportunity interest cost is about 10 to 12 percent.

At present, the total Horsens community budget is 225 million Dkr. About half of that is spent for education. Thus, the 18 million Dkr spent so far for the waste-to-energy system is a relatively small item. In presenting the project to the public, it was estimated that it would involve a daily per-capita cost of about 1.5 Dkr/day (25 cents/day). The new wastewater treatment plant costs about the same. The citizens readily accepted this cost of a cleaner environment which totaled less than the 12 to 14 Dkr ($2.00 to $2.33) cost of a pack of cigarettes!

APPENDIX A

NEW PLANT AT AARHUS-NORD

APPENDIX A

NEW PLANT FOR AARHUS-NORD

An expansion of some of the methods evolved at Horsens is embodied in the new plant at Aarhus Nord scheduled to be completed in early 1978. The Aarhus Nord plant is about km north of Horsens.

Figure 13-A1 is a cross section of the Aarhus Nord plant. As with the Horsens plant, this much larger plant will dry sludge and provide hot water for district heating. A distinct difference from Horsens is that the Aarhus-Nord plant uses a water-tube boiler instead of a firetube boiler. However, there are no water-tube walls in the furnace.

The design capacity is for 37,0000 tonnes/yr (40,700 tons/yr) of municipal refuse, 18,000 tonnes/yr (19,800 tons/yr) of industrial refuse, and 8,100m^3/yr (2,140,020 gallons/yr) of sludge from a current population of 240,000.

There are two smaller batch-type units in the basement: one for pathological and the other for nontoxic oily and grease wastes.

There are two complete refuse and sludge lines, each having a rated capacity of 8 tonnes/hr (8.8 tons/hr). Thus, the total rated refuse-burning capacity is 384 tonnes/day (422 tons/day).

The two boilers are of three-pass design built by Volund at Esbjerg, Jutland, only 100 km (62 mi) west. The first two vertical passes are completely open radiation passes partially lined with water tubes. The final vertical pass is a conventional one containing bundles of horizontal 8 mm (1.5 in) tubes that will be cleaned by falling steel or aluminum pellets. A major concept in this design is to minimize the danger of tube corrosion, even though the output water temperature will be relatively low, ranging from 150 C to 210 C (302 F to 410 F).

The hot water is to be piped 5.5 km (3.4 mi) to a distributing station at Vorrevangen where a heat exchanger will produce 90 C (194 F) water to be distributed at a rate of about 25 Gcal/hr (99.2 M Btu/hr) (104.7 GJ/hr) to about 2,500 residences and flats. The pipeline and heat exchanger cost 18 million Dkr ($3 million) in 1977. The oil-heated

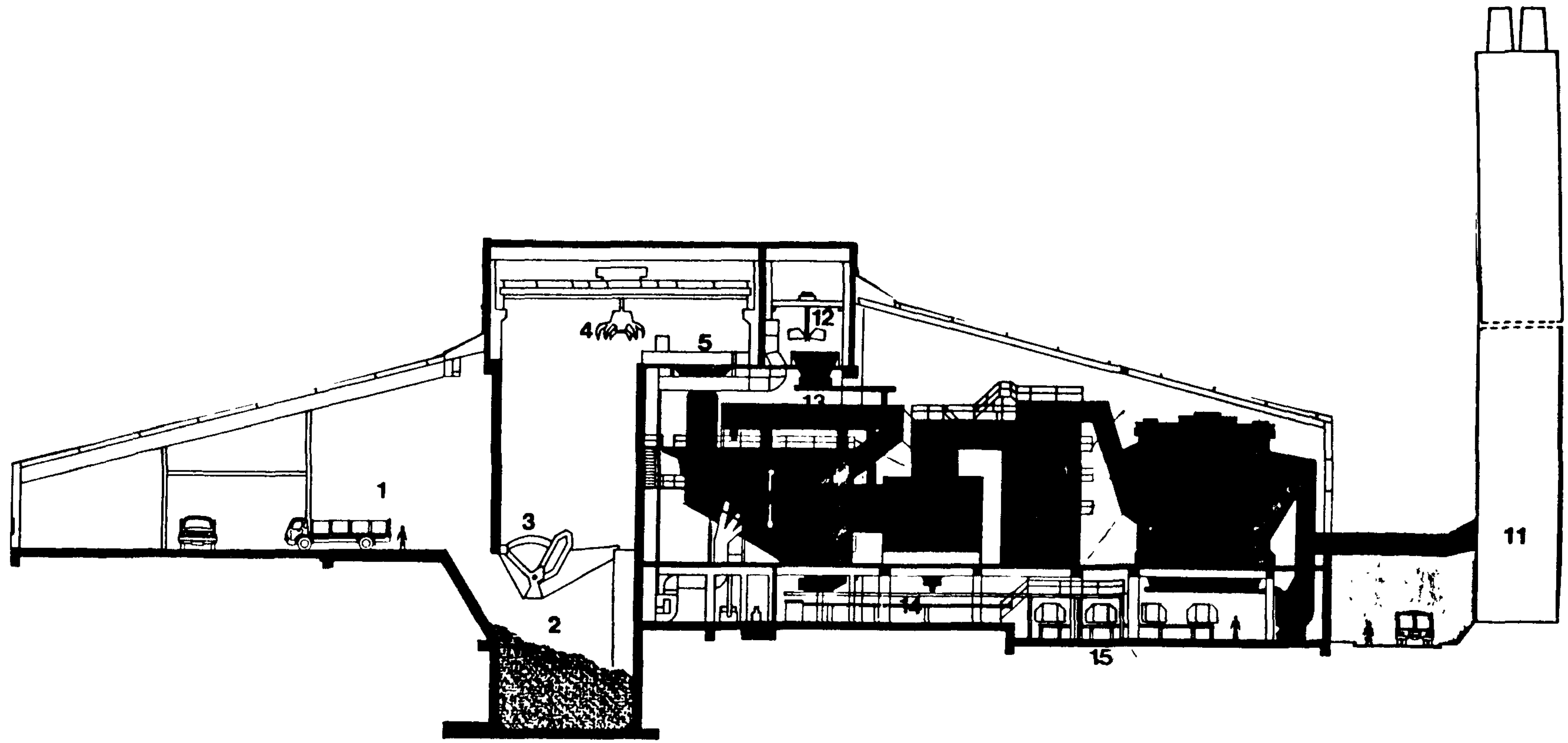


FIGURE 13-A1. AARHUS-NORD PLANT

1. Tipping Hall
2. Refuse Bunker
3. Bulky Refuse Shear
4. Crane and Bucket
5. Charging Hopper
6. Furnace
7. After-Combustion Chamber
8. Waste Heat Boiler
9. Electrostatic Precipitator
10. Induced Draft Fan
11. Chimney
12. Sludge Crane
13. Sludge Dryer
14. Residue Conveyor
15. Residue Containers

district heating system already serves about 4,000 units, about 70 percent of them individual residences, and is expected to be expanded in a few years to 5,000 or 6,000 units. Only 10 percent of the Aarhus-Nord energy will need to be wasted in the summer.

Development of the Aarhus System

Although Denmark has been a world leader in recovering useful energy from the burning of community wastes, mostly for district heating, very little for electricity, the recent Aarhus history is an interesting example of how some communities all over the world have been avoiding incineration. This policy usually stems from the attitude that it is wrong to burn waste when some useful product such as compost and metals and glass can be recovered from it. Accordingly, in 1957, a Dano, rotary drum, compost plant was built only 1 km (0.6 mi) west of the center of Aarhus. It still operates but will be closed in 1980 because most of the compost cannot be either sold or donated and the landfills for the compost have become objectionable.

In 1965, an English shredder was added to the system and sewage sludge was introduced to the Dano process. There have since then been some odor problems from the compost landfills.

In 1970, the Danish trend of consolidation of communities reached Aarhus and 21 other towns were brought into the Aarhus AMT (region). The AMT Council had the authority to direct changes in the waste disposal practice of these towns which usually used landfills. But no one wanted new landfills nearby. On June 1, 1973, a new regional waste disposal plan was issued which determined on the construction of Aarhus-Nord. It was to begin operation in mid-1977, but owing to a very serious construction crane accident in early 1977, startup was delayed until February 1, 1978. The plan also includes construction soon of Aarhus-Syd, south of town.

Six different sites were considered for each of the north and south plants. They had to be near to district heating centers. The north site is 80 m (262 ft) above sea level. The 100 m (327 ft) chimney provides for good dispersal of residual emissions.

The authors are indebted to the following officials of the City of Aarhus for their discussion and tour of the Aarhus-Nord construction site: O. Villadsen, Chief Engineer; and T. Truelshoi, Principal Engineer for Wastes.

APPENDIX B

INDUSTRIAL AND HAZARDOUS WASTE TRANSFER STATION AT HORSENS AND TREATMENT AT NYBORG, DENMARK

- Horsens Transfer Station Picture
- Nyborg, Denmark Plant Brochure
- Von Roll/Environmental Elements Literature

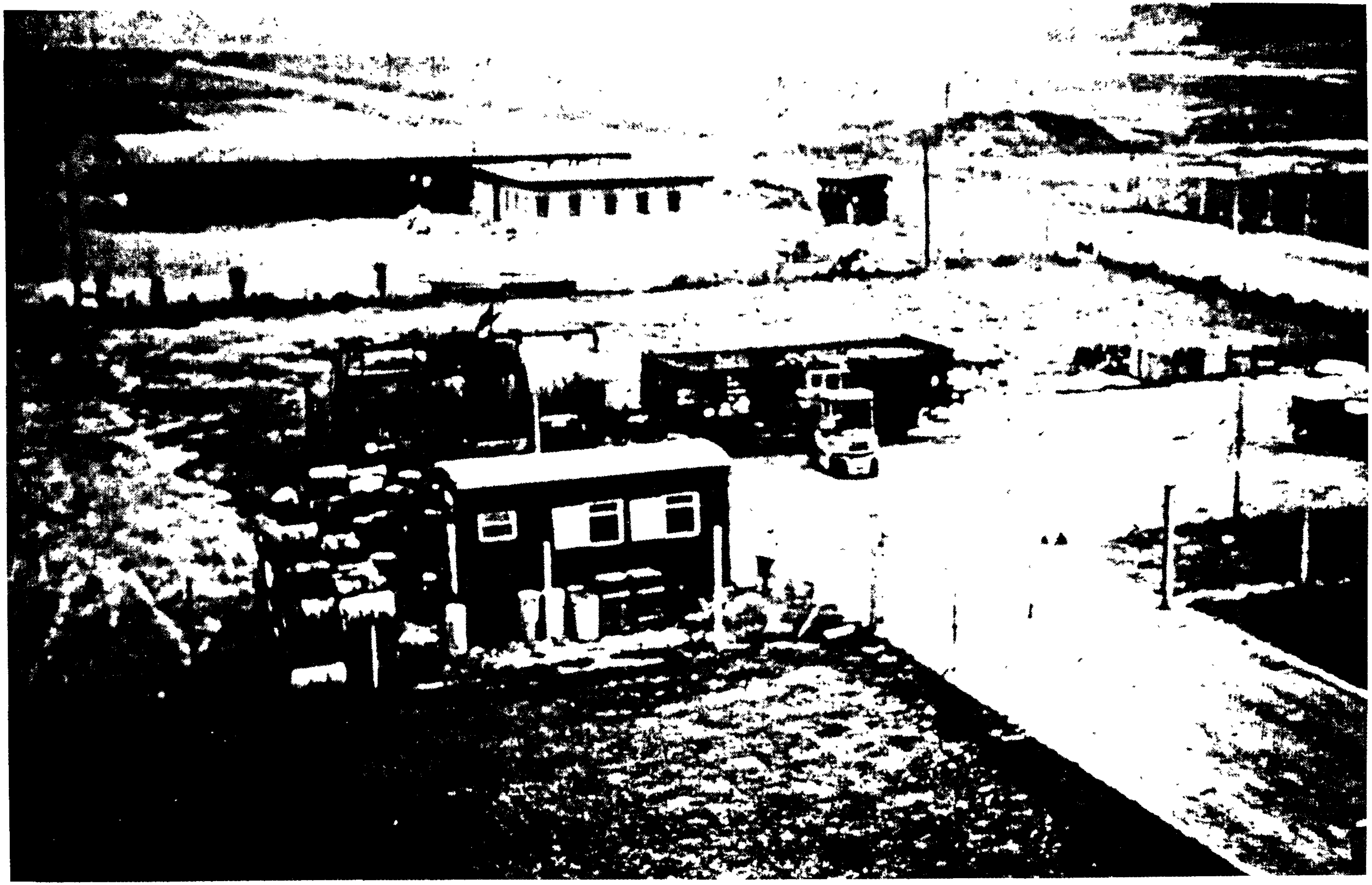
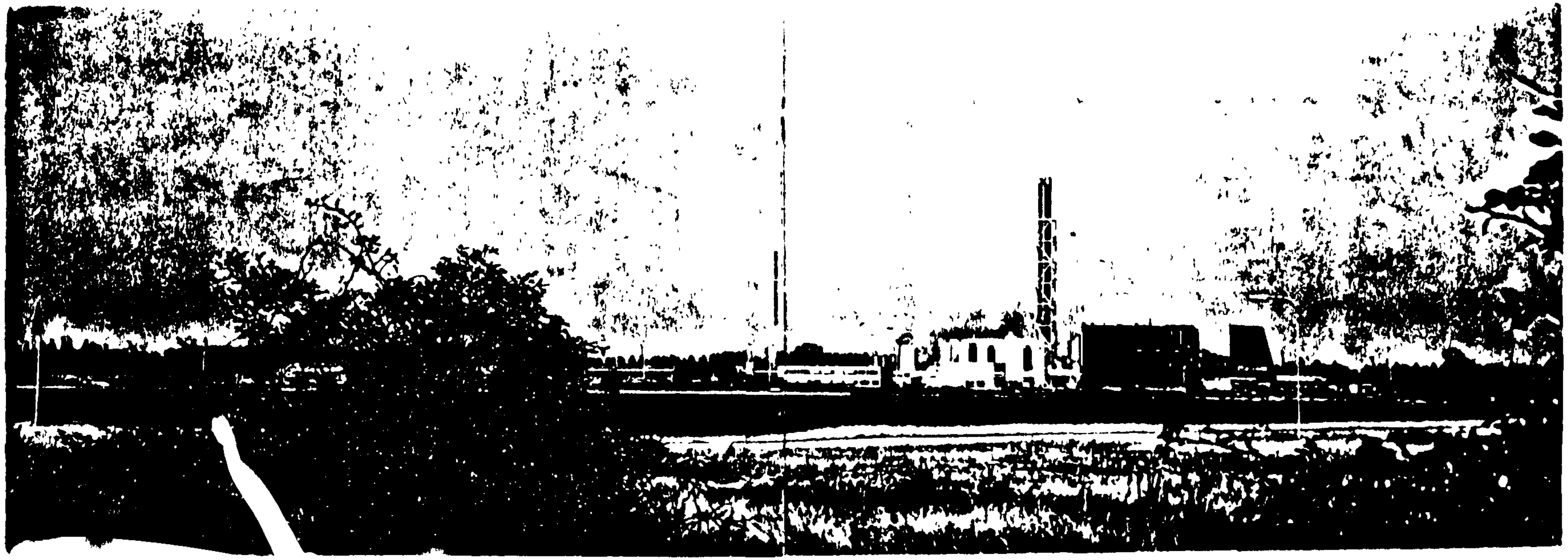


FIGURE 13-B 1. TANKER FOR COMPATABLE WASTE OILS AND FLAT BED CAR FOR NON-COMPATABLE BARRELS OF WASTE AT THE CITY OF HORSENS INDUSTRIAL AND HAZARDOUS WASTE TRANSFER STATION



NYBORG, DENMARK INDUSTRIAL AND HAZARDOUS WASTE TREATMENT CENTER

OWNED AND OPERATED BY THE NATIONAL ASSOCIATION OF MUNICIPALITIES

A Danish Pioneering Achievement

Denmark is a small country surrounded by sea, divided into numerous islands and peninsulas with streams and lakes. Like people of other nations, we Danes are proud of our countryside and, therefore, the fight against pollution has become a national cause.

Denmark has laws and regulations against the pollution of air, water, land, and against noise pollution, but laws and regulations are one thing; to ensure their enforcement is rather more difficult.

Industrial waste products vary widely, some are inoffensive, others toxic, some even highly dangerous. There are also many other sources of toxic waste; even private households contribute their share.

For many years toxic waste has ended in the sewers or on the refuse dump, because there were simply no other means of disposal.

Discussions regarding pollution opened up a dismal perspective, and problems exposed by the press, radio, and television, made the path clear for an environmental policy in Denmark.

A Ministry of Environment was formed, new laws were passed and all municipalities jointly decided to establish a nation-wide collection system for oil and chemical waste and a modern treatment plant for special waste. The result of these endeavours has been the foundation of Kommunekemi in Nyborg.

As the first country in the world Denmark can now offer every citizen and every industry or institution the facility of sending toxic waste for treatment and the certainty that it will be neutralized by specially trained personnel using the most modern equipment available. If the waste contains any components of value, these will be separated with economic advantage to the supplier and ultimately, of course, to the Danish nation.

This publication is intended to make Kommunekemi - a Danish Pioneering Achievement - known to those interested in the protection of environment.

Oil or chemical waste is collected either at the municipal collection sites or is sent directly to Kommunekemi from the individual industrial plants.

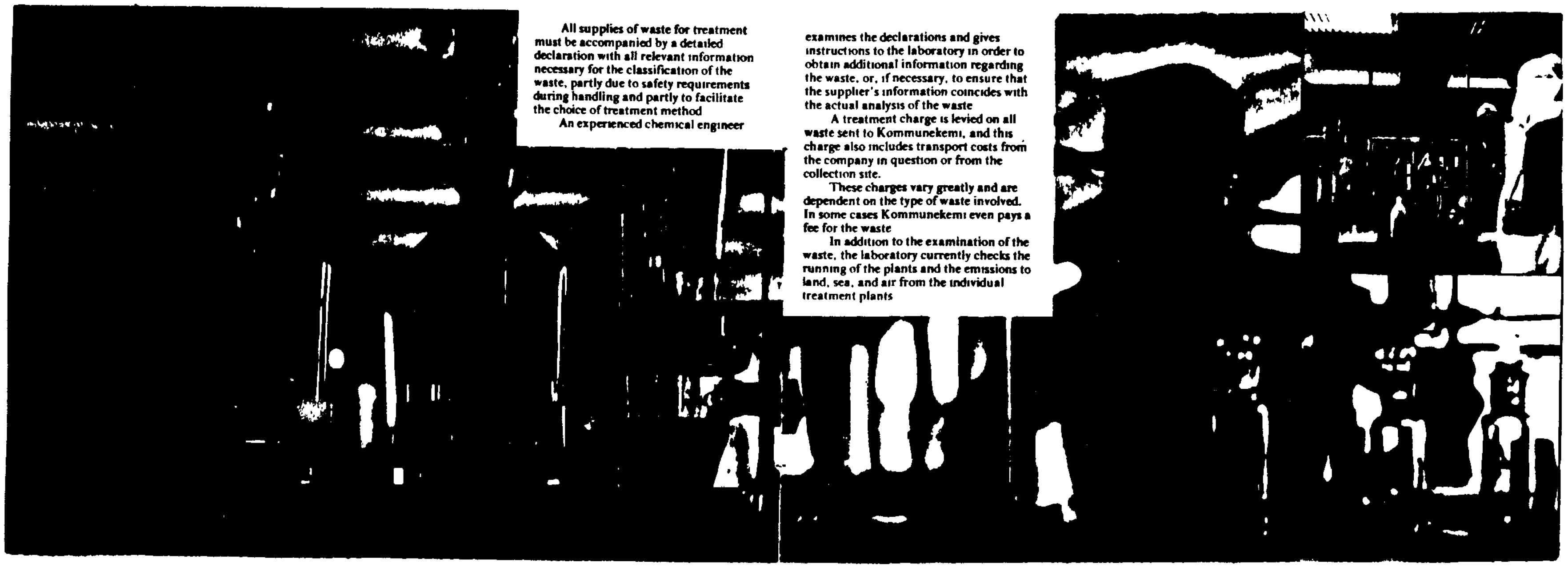
The municipal collection sites are of two categories: 1) 20 large central sites distributed throughout the country and open daily for the reception of waste. Collection sites of this category are common to several municipalities and are intended for the reception of industrial waste. 2) In every municipality there is at least one collection site where private householders may deposit refuse.

The waste sent to Kommunekemi via the municipal collection sites arrives by rail in tank wagons or goods wagons. Sample cans of the contents accompany the tank wagons and contain the same waste as in the tank.

When the waste is transported in drums, samples are taken to the laboratory for analysis before the waste can be treated.

After emptying, the wagons are cleaned inside before being returned to the suppliers. The drums which can be completely emptied and are in good condition are returned to the municipal sites, while those heavily damaged are sent to the steel mills at Frederiksværk for smelting. Drums which cannot be emptied are sent to the incinerating plant.

Inorganic chemical waste is mainly received in 725 litres' plastic pallet tanks which, after emptying and cleaning in the inorganic plant, are returned for re-use.



All supplies of waste for treatment must be accompanied by a detailed declaration with all relevant information necessary for the classification of the waste, partly due to safety requirements during handling and partly to facilitate the choice of treatment method

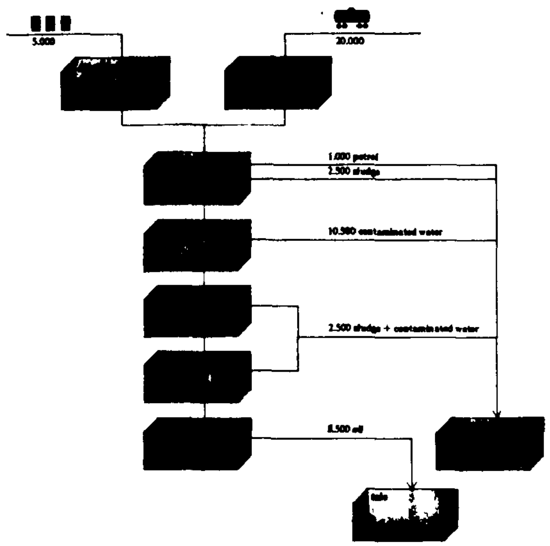
An experienced chemical engineer examines the declarations and gives instructions to the laboratory in order to obtain additional information regarding the waste, or, if necessary, to ensure that the supplier's information coincides with the actual analysis of the waste

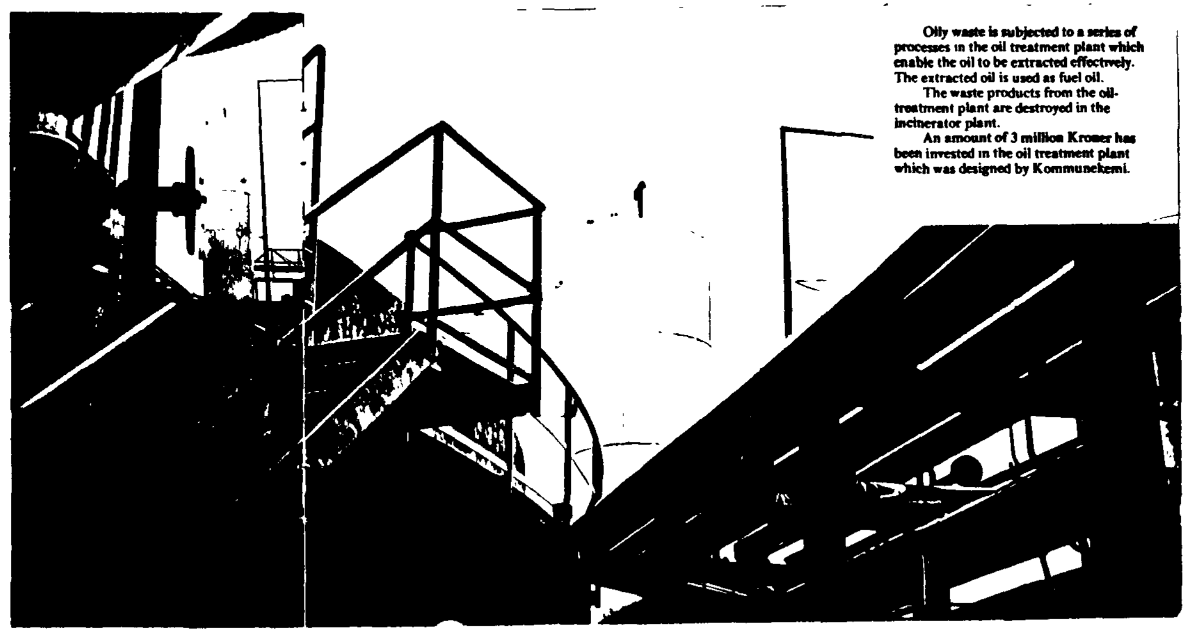
A treatment charge is levied on all waste sent to Kommunekemi, and this charge also includes transport costs from the company in question or from the collection site.

These charges vary greatly and are dependent on the type of waste involved. In some cases Kommunekemi even pays a fee for the waste

In addition to the examination of the waste, the laboratory currently checks the running of the plants and the emissions to land, sea, and air from the individual treatment plants

OIL TREATMENT PLANT (tons/year)

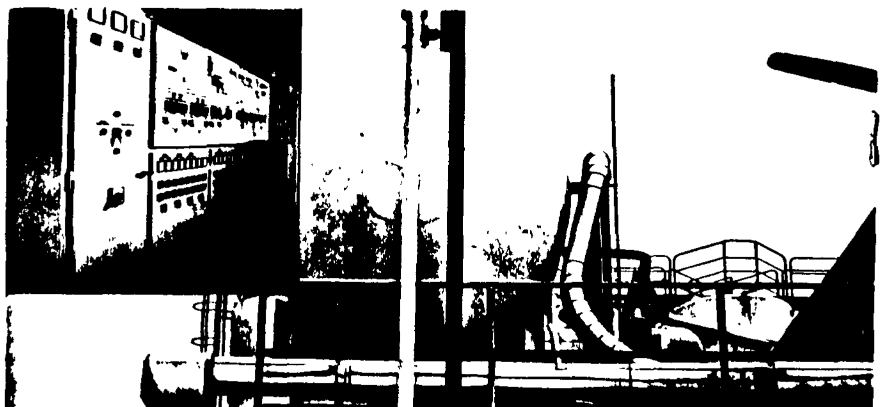




Oily waste is subjected to a series of processes in the oil treatment plant which enable the oil to be extracted effectively. The extracted oil is used as fuel oil.

The waste products from the oil-treatment plant are destroyed in the incinerator plant.

An amount of 3 million Kroner has been invested in the oil treatment plant which was designed by Kommunekemi.



Treatment of rejected pickling baths and baths from the electroplating industry and sludge from its water effluent treatment systems takes place in the plant for inorganic chemical waste.

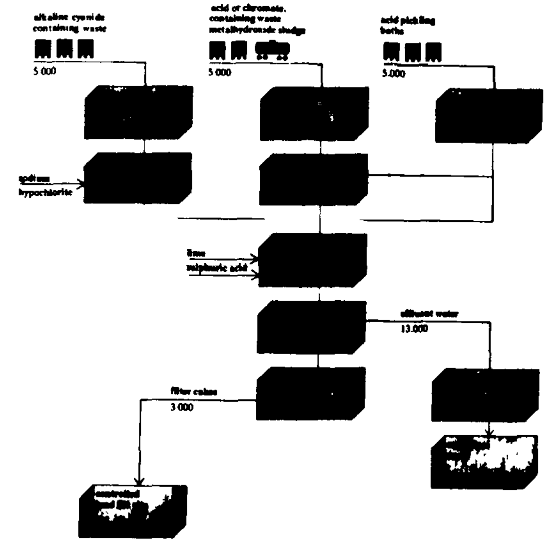
Treatment takes place in charges and is commenced by a detoxification by destruction of cyanide and chromate. Treatment of the chromate takes place by a sort of recycling, as other types of waste are suitable for this purpose.

When detoxification is complete, the metals which mainly are iron, zink, lead, nickel, chrome, and copper, are precipitated as metal hydroxides. These metal hydroxides are drained off in a filter press and the clean filtrate is led into the local sewage system.

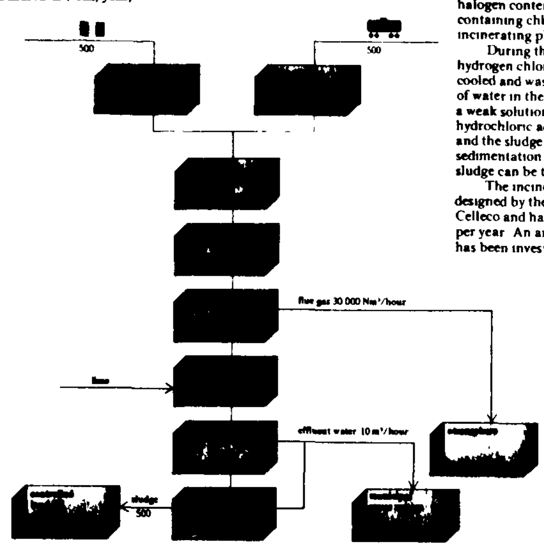
The filter cakes are stored in a special section of Kommunekemi's site separate from other refuse. The filter cakes contain the above metals and at the moment methods are being developed to enable the recovery of these metals on a profitable basis.

The treatment plant has been designed by the German Company Gottfried Bischoff KG, and is capable of processing 40.000 tons per year. At the present time 6 million Kroner has been invested in the plant.

INORGANIC PLANT (tons/year)



INCINERATOR PLANT II (tons/year)

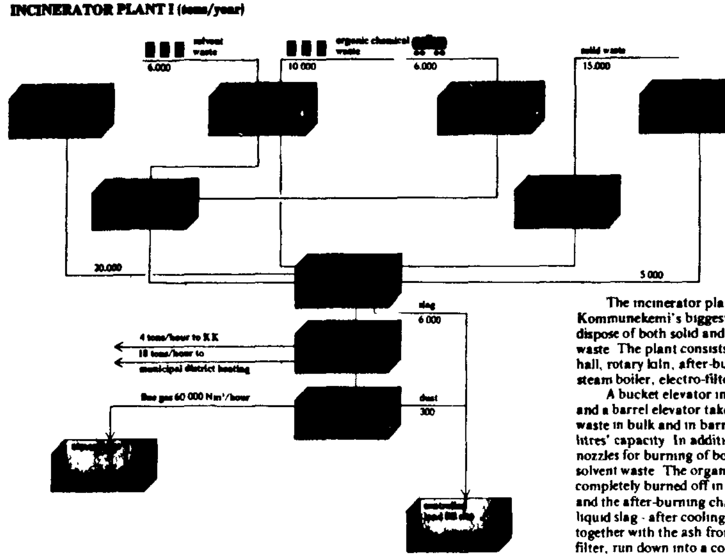


All pumpable organic waste with halogen content, mainly polluted solvent containing chlorine, is treated in the incinerating plant II.

During the incinerating process, hydrogen chloride is formed and this is cooled and washed out in large quantities of water in the rinsing tower thus forming a weak solution of hydrochloric acid. The hydrochloric acid is neutralized by lime and the sludge thus formed is removed in a sedimentation tank. After draining the sludge can be taken to the refuse site.

The incinerator plant has been designed by the Swedish Company AB Celleco and has a capacity of 9000 tons per year. An amount of 3 million Kroner has been invested in the plant.

INCINERATOR PLANT I (tons/year)

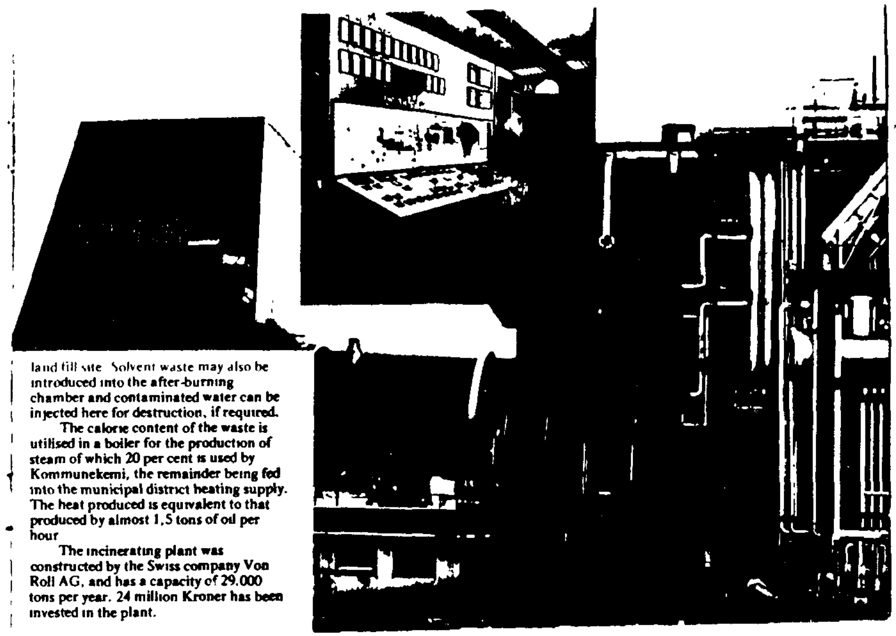


The incinerator plant I is Kommunekemi's biggest plant and can dispose of both solid and liquid organic waste. The plant consists of a loading hall, rotary kiln, after-burning chamber, steam boiler, electro-filter, and a chimney.

A bucket elevator in the loading hall and a barrel elevator takes care of solid waste in bulk and in barrels of up to 200 litres' capacity. In addition there are nozzles for burning of both sludge and solvent waste. The organic waste is completely burned off in the rotary kiln and the after-burning chamber. The liquid slag - after cooling in water - together with the ash from the electro-filter, run down into a container and is afterwards transported to the controlled land fill site. Solvent waste may also be introduced into the after-burning chamber and contaminated water can be injected here for destruction, if required.

The calorie content of the waste is utilised in a boiler for the production of steam of which 20 per cent is used by Kommunekemi, the remainder being fed into the municipal district heating supply. The heat produced is equivalent to that produced by almost 1,5 tons of oil per hour.

The incinerating plant was constructed by the Swiss company Von Roll AG, and has a capacity of 29.000 tons per year. 24 million Kroner has been invested in the plant.

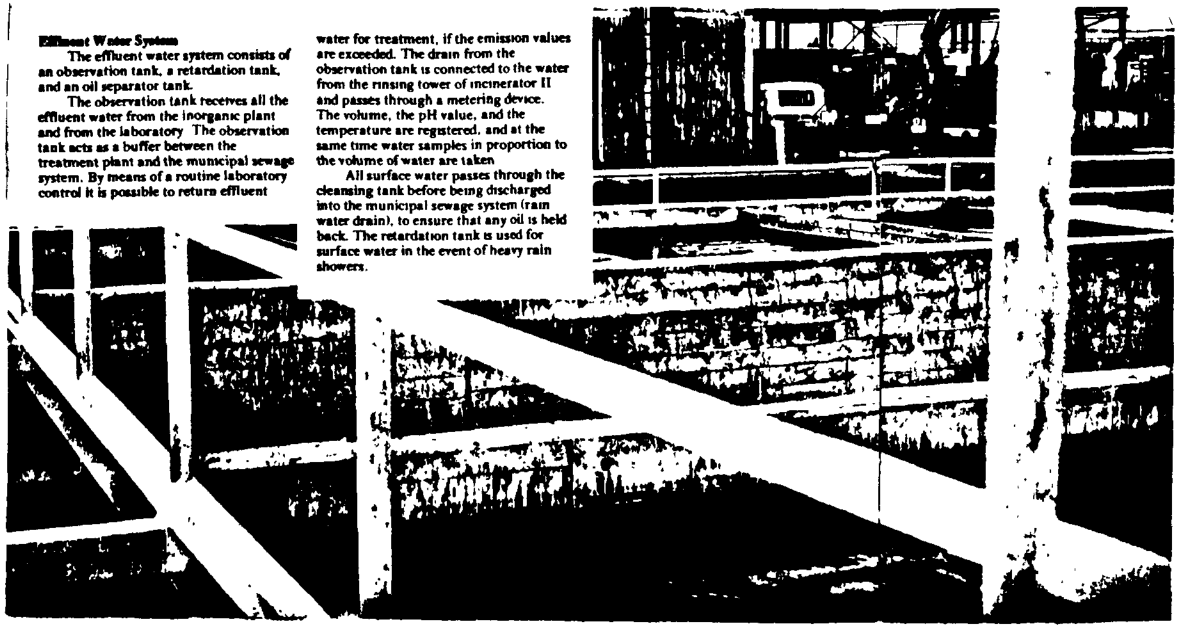


Effluent Water System

The effluent water system consists of an observation tank, a retardation tank, and an oil separator tank.

The observation tank receives all the effluent water from the inorganic plant and from the laboratory. The observation tank acts as a buffer between the treatment plant and the municipal sewage system. By means of a routine laboratory control it is possible to return effluent water for treatment, if the emission values are exceeded. The drain from the observation tank is connected to the water from the rinsing tower of incinerator II and passes through a metering device. The volume, the pH value, and the temperature are registered, and at the same time water samples in proportion to the volume of water are taken.

All surface water passes through the cleansing tank before being discharged into the municipal sewage system (rain water drain), to ensure that any oil is held back. The retardation tank is used for surface water in the event of heavy rain showers.



site is ...
Nyborg in an are...
The final location has been the subj...
a long series of preliminary investigat...
and the ideal site was found at Klintho...
an area of approximately 15 hectares where, until recently, agricultural lime was digged out.

After filling with refuse the area is covered with soil and in this way it is possible to re-create the landscape.

There are types of waste which cannot be treated in the plants that Kommunekemi has at its disposal to-day. These types of waste may also be sent to Kommunekemi who can store the waste in an environmentally correct manner until new treatment plants are constructed.

Kommunekemi is also working on projects which will make it possible to win valuable substances from the waste products, so that these substances may be re-used in production and thus economize on Denmark's imports of raw materials.

Financing of Kommunekemi in the construction period was made possible by means of a loan of 67 million Kroner from the Municipal V.A.T. Fund. In addition, the Municipalities have granted a direct loan of approximately 2 million Kroner.

Kommunekemi is a Limited Company.

The shareholders are the National Association of Municipalities, The City of Copenhagen, The Borough of Frederiksberg, and the Danish Gasworks Tar Company at Nyborg.

Kommunekemi a/s

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Telefon (09) 31 12 44

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Frands Harrebek

Consulting Engineers.
Oilconsult A/S
Mogens Balslev A/S
Cowiconsult A/S

Regional Industrial Waste Treatment Centre

A wide-spread and well-organized collecting service ensures that all industrial wastes from a particular region or even from an entire country can be transported to, and ecologically treated in, an industrial waste treatment centre Such centralization is the economical prerequisite for a modern, large-scale designed industrial waste treatment plant which complies with all requirements A centrally placed facility of such proportions should be capable of processing liquid, emulsified, pasteous and solid wastes of every kind In our case, we had to cope with the treatment of the industrial wastes of a medium-sized country comprising numerous islands and a peninsula (Denmark)

Problem

Treatment of 80,000 metric tons per year of industrial waste, the aim being to recover as much raw materials as possible for recycling

The following wastes are to be treated
a) mineral waste oils
b) polluted organic solvents, residues from destillation and chemical side products
c) paint and varnish residues, waste facts, bitumen, resin, glue, oil sludge, etc
d) chlorinated hydro carbons (liquid)
e) anorganic wastes, galvanic sludge, chromates and cyanides
f) solid waste, packing materials, synthetics, chemical side products, oil-polluted earth, etc
The wastes are delivered in tank lorries, rail tank cars as well as in barrels and containers

Aim

- recovery of as much raw materials as possible
- combustion of residuals with utilization of the produced energy under observance of existing Regulations with respect to burn-out and air purity
- most economical and self-supporting operation
- concept and design of the plant has to allow for easy adaptation to the ever-changing conditions in quantity and composition of refuse

Solution

The process scheme (opposite page) shows the processes selected for the various wastes and how they are arranged The main processing stages are as follows
- delivery, inspection and unloading
- intermediate storage
- .preparation
- decanting
- neutralization and decontamination
- intermediate storage
- combustion in plant I
- combustion in plant II

The combustion part was divided into two independently operating installations, whereby in the combustion chamber of plant II only highly chlorinated hydro-carbons are burnt Because of this solution, only a relatively small amount of flue gas of known composition has to be scrubbed Flue gas from the combustion of the remaining wastes contains comparatively few noxious substances and, therefore, needs not to be scrubbed, "dry" dedusting is sufficient here.

□

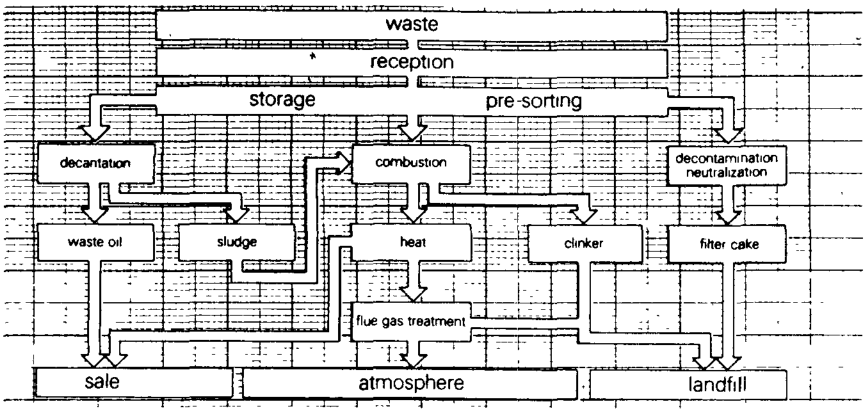
Legend to diagram

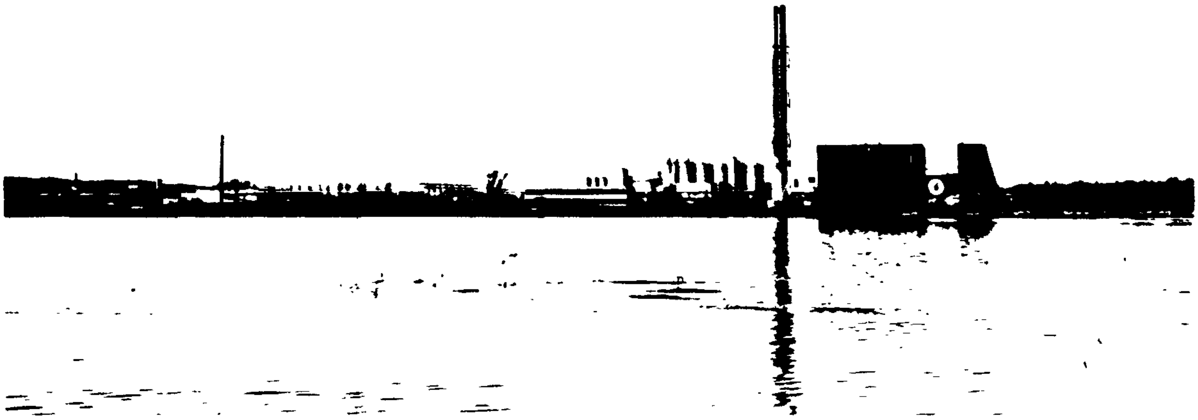
Pre-treatment

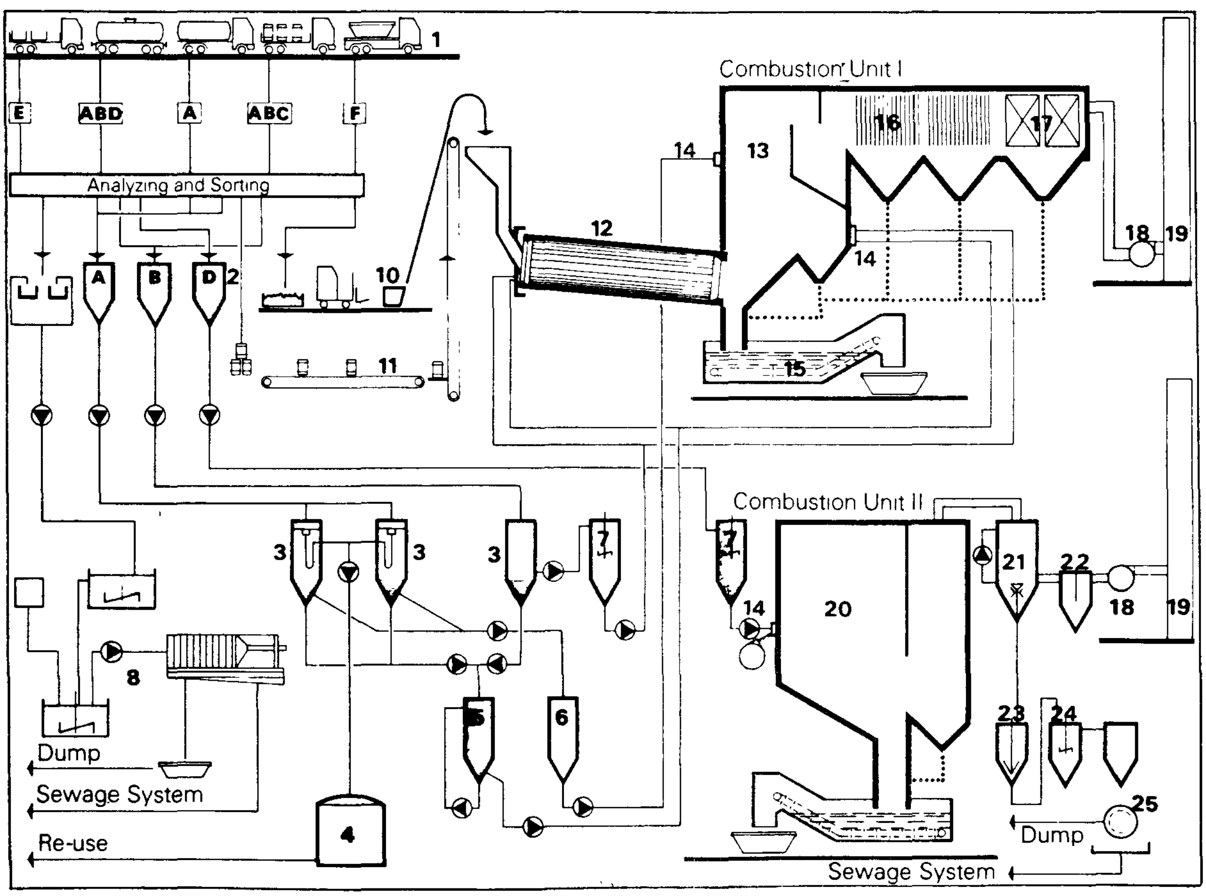
1 reception of material groups A–F
2 intermediate storage
3 decantation of material groups A, B and D
4 oil-storage tank
5 sludge silo
6 intermediate tank
7 agitator tank
8 neutralization, decontamination and filter press for material group E

Combustion

10 solids charging (material group F)
11 barrel charging (material group C)
12 rotary kiln
13 after-burning chamber
14 special burner
15 slag and ash removal
16 tail-end boiler
17 flue-gas dedusting
18 induced draft fan
19 stack
20 combustion chamber for material group D
21 flue-gas scrubber
22 cyclone
23 pre-thickener
24 neutralization
25 after-treatment and drum filter

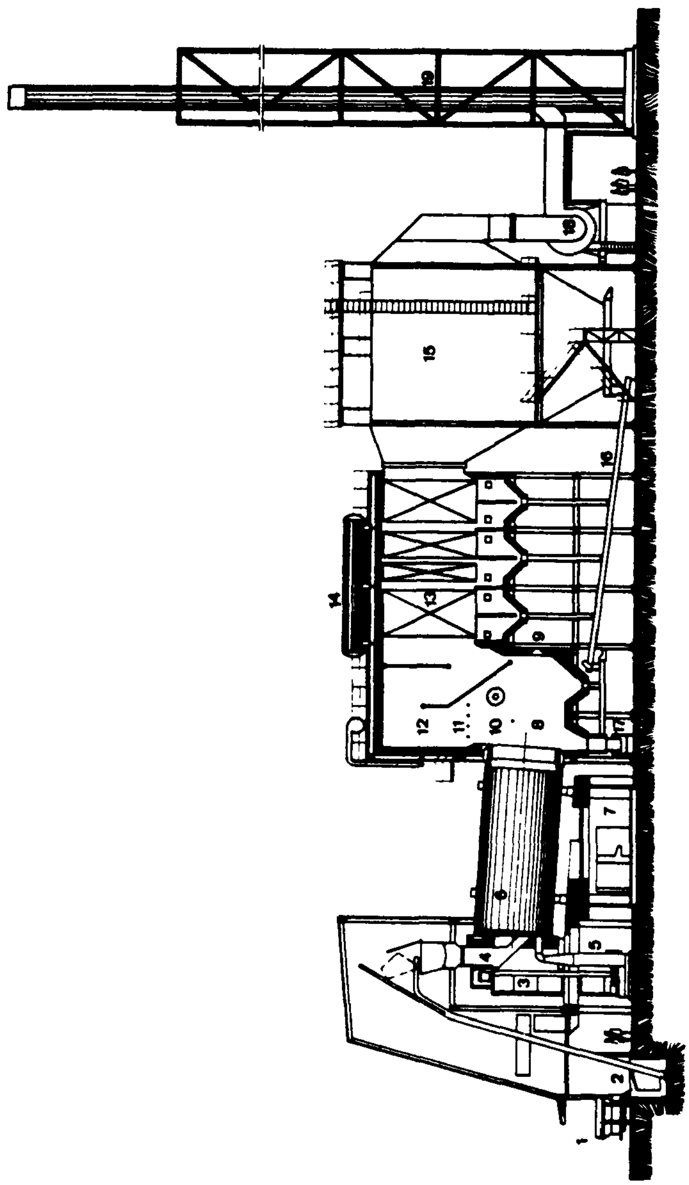

waste
reception
storage
pre-sorting
decantation
combustion
decontamination
neutralization
waste oil
sludge
heat
clinker
filter cake
flue gas treatment
sale
atmosphere
landfill




Combustion Unit I
Analyzing and Sorting
E
ABD
A
ABC
F
Combustion Unit II
Dump
Sewage System
Re-use
Dump
Sewage System

HAZARDOUS WASTE DISPOSAL PLANTS

ROTARY KILN SYSTEM



ENVIRONMENTAL ELEMENTS CORPORATION

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

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

Revised Dec. 78

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

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

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

Revised Dec. 78

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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