308 BILLION TON-HOURS OF
REFUSE POWER EXPERIENCE:
A REVIEW OF THE LONG-TERM OPERATING
RECORD AT DUESSELDORF CITY

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ABSTRACT

District heating is a very lucrative business in Europe, with many extensive networks already in place, especially in Scandinavia and Russia. Refuse power represents an energy alternative which is readily available and which, in conjunction with electrical power generation and district heating networks, can address the twofold problem of waste disposal and energy supply within the framework of community control.

One installation, the Flingern Refuse Power Plant in Düsseldorf, West Germany, is singled out for an in-depth treatment because of its unique long-term operating history.

INTRODUCTION

At the present, there has been much excitement created in the United States solid waste market by the advent of such new technologies as pyrolysis and refuse derived fuel (RDF). However, these technologies are largely unproven, and therefore their application is associated with high technical and economic risks. For this reason, it appears most appropriate to review refuse power as the one technology which is most widespread and already well proven; that is, the mass burning of unprepared wastes on specially designed grate systems, and the raising of superheated steam in integral boilers.

It has been reported that, on a worldwide basis, there are over 260 refuse power plants in operation today which embody this technology [1]. While this number is impressive, there are only a few such plants which operate on a very large scale; that is, plants which process over 300,000 tons (2.72 x 10^8 kg) of solid waste each year and which, in doing so, have performed well and consistently during a period of 10 years or more to produce high quality energy for sale.

The Flingern Refuse Power Plant (RPP) belongs in this select group, having been a large and dependable supplier of refuse derived steam for the cogeneration of electricity and for district heating for over 12 years. As of December, 1976 this Düsseldorf plant had accumulated 308 billion ton-hr* (2.79 x 10^14 kg-hr) of operating experience, and it is the purpose of this paper to document, for the first time, this astonishing accomplishment.

*This total does not reflect substantial pilot plant experience.
BACKGROUND

The City of Duesseldorf is the capital of the State of North Rhine Westphalia in the Federal Republic of Germany (FRG). Populated by 655,000 residents, this city sprawls along both banks of the Rhine River and connects with the western fringes of the industrial Ruhr district. With large concentrations of industry and commerce, Duesseldorf is also one of the major transportation hubs in Europe.

Like many other cities, Duesseldorf was rebuilt and experienced major expansion after World War II. As its population grew and its standard of living increased, solid waste became a major problem. In addition to increased per capita generation rates, the solid waste changed in its nature primarily due to the influx of paper and plastics, a reduction in moisture content. This resulted in increased energy content, and also, due to decreased density, in an ever increasing volume of solid waste. As a result, the need for the disposal of municipal solid waste (MSW*) grew from 149,000 short tons per year (STPY) (1.35 $\times 10^8$ kg per year) to 400,000 ton/year (3.63 $\times 10^8$ kg per year) in about 20 years, while the energy content of this waste more than doubled from 1600 Btu/lb (3.72 $\times 10^3$ kJ/kg) to about 3300 Btu/lb† (7.68 $\times 10^3$ kJ/kg) in the same period.

Table 1 provides more detail on this background.

PROJECT HISTORY: EVOLUTION OF THE DUESSELDORF SYSTEM

In 1957, the city administration responded to the solid waste challenge by commissioning a study to research alternatives to the landfilling of raw waste. This study quickly determined that refuse power would be the most environmentally accepted and cost-efficient approach. After this conclusion, development of the Duesseldorf system followed a classical three-step pattern.

First, in 1958 the Department of Sanitation shipped sample refuse by railroad, to Geneva, Switzerland, for test burns in already existing facilities. Unfortunately, these tests were unsatisfactory, primarily due to incomplete burnout of the Duesseldorf-type wastes processed.

Second, in 1960 the City Council decided to build its own pilot plant at the old Flingern Electrical Power Station (EPS), despite the disappointing news from Geneva. By forming a partnership with Duerr Werke and Vereinigte Kesselwerke A.G. (VKW), the city opted to develop a new refuse power system which would result in a superior burnout of a wide variety of solid wastes. From 1961 to 1965, this pilot plant successfully processed 204,600 short tons (1.86 $\times 10^8$ kg), or 25 percent of the city’s refuse. The combination of a novel 4-roller grate and a short travelling grate mounted under an existing 4-drum power plant boiler, of 1926 vintage, was used to generate low pressure steam for electrical power production.

Third, while the pilot operation was underway, the Stadtwerke A.G. (Municipal Works Company), under contract to the Department of Sanitation, initiated the design of a full-scale refuse power plant at a new site called Flinger Broich, in Flingern, a borough of the city of Duesseldorf. The use of the travelling grate was found to be unnecessary, and instead the roller grate system was lengthened to include three additional rollers for a total of seven. This improved roller grate system, together with independent speed and air flow controls for each roller, became known as the “Duesseldorf Roller Grate System.” Construction followed a multi-phased schedule to comply with the population growth and its associated need for additional plant capacity.

Construction of Phase I, for four identical processing lines, was completed in 1965, permitting shut-down of the pilot plant.

Phase II construction entailed the installation of a fifth and larger processing line to accommodate increased refuse quantities with increased heating values. Figure 1 depicts the Flingern RPP at the end of Phase II construction.

As part of the Phase III construction, a sixth and final processing line is planned with special provisions for boiler technology research. Phase III is expected to commence in 1978 with the installation of a bal­ing press and modifications in the ash removal sys­tem. During 1980, the Flingern RPP is expected to be completed with its full design capacity installed.

Construction of the Flingern RPP permitted the closing of four older landfills and an extension of disposal services beyond the city limits. A number of neighboring municipalities joined with the city to form what can be considered a regional waste

* In this context, MSW is defined as a mixture of waste materials which according to their origin can be classified as about 67 percent residential/institutional and about 22 percent commercial/industrial. The remaining 11 percent is constituted of bulky wastes, sweepings, tires, etc. MSW is herein synonymous with Refuse.

† Lower heating value
<table>
<thead>
<tr>
<th>Year</th>
<th>Residents</th>
<th>Residents</th>
<th>Kq. per Co.</th>
<th>SPP</th>
<th>SPP</th>
<th>N/A</th>
<th>N/A</th>
<th>N/A</th>
<th>N/A</th>
<th>N/A</th>
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<td>1951</td>
<td>541,500</td>
<td>541,000</td>
<td>5.65</td>
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<td>N/A</td>
<td>+1.395</td>
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<tr>
<td>1956</td>
<td>664,000</td>
<td>664,000</td>
<td>12.36</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>+1.620</td>
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<td>1961</td>
<td>702,600</td>
<td>702,900</td>
<td>19.42</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>+1.20</td>
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<tr>
<td>1965</td>
<td>699,000</td>
<td>698,000</td>
<td>26.48</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>2.250</td>
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### TABLE 1 DUESSELDORF GREATER METROPOLITAN AREA POPULATION AND SOLID WASTE STATISTICS

<table>
<thead>
<tr>
<th>Statistic</th>
<th>City of Düsseldorf</th>
<th>Outside Municipalities</th>
<th>Greater Metropolitan Area</th>
<th>Population Served</th>
<th>Wastes Disposed</th>
<th>Waste Characteristics</th>
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</table>

**Notes and Sources:**

1. Not available or not applicable.
2. Staffed by the municipal government.
3. Staffed by a private contractor.
4. Annual statistics submitted by operator to user.
6. Municipal solid waste: refuse comprised mainly of residential (2/3) and commercial/industrial (1/3) wastes, including street sweeping.
7. Per calendar day.
8. Disposal Types:
   - A. Sanitary landfill only.
   - B. Sanitary landfill and Pilot Plant.
   - C. Refuse Power Plant and Sanitary Landfill.
10. Average annual refuse weight contained in standard 110-liter receptacles rented by residents by Department of Sanitation.
11. Using "MSW Collected" and "MSW Disposed" as basis.
12. Mostly street sweepings during initial 1966 to 1969 period; thereafter, significant amounts of combustibles bypassed due to lack of processing capacity in BMP. Generally, about 1/3 of sweepings is processed while remainder is landfilled.
13. Arithmetic average for 11-year period calculated as: $\bar{X} = \frac{\sum X}{n}$. $(11/21) (14)$
14. Percentage change over 11-year period calculated as: $\% = \frac{X_{11} - X_{01}}{X_{01}} \times 100%$.
15. Coefficient of variability for 11-year period calculated as: $\% V = \frac{X_{11} - X_{01}}{X_{01}} \times 100%$.

**Sources and Sites:**


**Notes:**

- "Strassenreinigung und Müllentsorgung."
disposal operation. The impact that the plant had on the extension of landfill life will be discussed in a later section of this paper under "Operating Results."

In 1969, the plant completed processing of the first 1,000,000 tons (9.07 x 10^8 kg) of waste; in 1976, the first ten years of continuous operations were concluded, and in 1977 the Flingern RPP passed the 100,000 hr operating mark. At the heart of this accomplishment was the evolution of the Duesseldorf Roller Grate System, which to date is the only one of its kind in the world. Use of the original patents which protected this technology was licensed by the City of Duesseldorf to VKW. Since that time, VKW has built 101 roller grate systems in 51 plants in 14 countries, on two continents. Unit processing capacities have grown from 11 and 14 short tons per hour (ton/hr) (9.98 x 10^3 and 1.27 x 10^4 kg/hr) at Duesseldorf to 33 ton/hr (2.99 x 10^5 kg/hr) at Stuttgart. Likewise, plant processing capacities have grown from the 1400 short tons per day (STPD) (1.27 x 10^6 kg/day) at Duesseldorf to 3200 STPD (2.90 x 10^6 kg/day) at Botlek, Holland. The latter is the largest refuse power and resource recovery plant operating in the world today.

Additional facts pertaining to the chronology of this highly successful project can be found in Table 2.

Applications of refuse power and the Duesseldorf System have not remained limited to cogeneration, but have been widened with the development of co-disposal plants where sewage sludge is processed together with refuse, and combined firing plants where conventional fossil fuels are used to supplement refuse derived energy [2].

Table 3 shows this diversity in the application of refuse power, depending mainly on local energy marketing conditions. It is worthy of note that the Botlek plant, in addition to electrical power genera-
TABLE 2 1400 STPD REFUSE POWER PLANT: PROJECT HISTORY

1957 to 1958----City Administration Researchs New Approaches to Dispose of Ever Increasing Refuse Volume and Ships Refuse by Railroad to Existing Facilities for Test Burns

1960--------City Council Decides to Build a Pilot Plant at Old Flingern Power Station and Forms a Partnership with Duerr Werke and VKW to Develop a New Refuse Power System which would Result in Superior Burnout

1961 to 1965----Operation of Pilot Plant: 204,600 Short Tons (ST) of Refuse Processed to Produce =210,000 ST of Steam at 220 PSIG and 660°F for Electrical Power Generation

Plant Disposes of 25% of City's Refuse, Operating 5-1/2 Days Each Week

1962--------Conceptual Design of Full-Scale Refuse Power Plant Begins for New Site at Flinger Broich

November 1963---Start of Phase I Construction (4 Processing Lines)

August 1965-----Shut-Down of Pilot Plant After 4-1/2 Years of Operation

November 1965---Completion of Phase I Construction

January 1966----Full-Scale Operation Commences

1969--------Plant Completes Processing of First Million ST of Refuse

Summer 1972-----Completion of Phase II Construction (Addition of Fifth Processing Line, Startup Late in August)

1973--------Plant Processes in Excess of 300,000 ST of Refuse Annually (Approximately 87% of Collections)

1976--------Plant Successfully Concludes First 10 Years of Continuous Operation Demonstrating Its Dependability in Disposing of Refuse and Producing Saleable Energy (Specific Steaming Rate = 2.07 lb/lb)

Summer 1977-----Plant Passes the 100,000 Hour Operating Mark Thus Accumulating 337 Billion Ton-Hours of Refuse Power Experience (345 Billion Ton-Hours if Pilot Experience is Included)

1978--------Start of Phase III Construction Anticipated:

(1) Installation of Sixth and Final Processing Line to Complete Plant

(2) Installation of Dry Scrubbing System to Upgrade APC System for Compliance with TA Luft 74

(3) Installation of Baling Press to Facilitate Bypassing of Undesirable Wastes
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>YEAR OF COMMISSIONING</th>
<th>REFUSE PROCESSING CAPACITY STPD</th>
<th>STEAMING CONDITIONS (1)</th>
<th>ENERGY MEDIUM AND APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DUESSELDORF</td>
<td>1965/72</td>
<td>1,400 (1,720)(2)</td>
<td>1,280 932</td>
<td>High pressure superheated steam for electrical power generation and district heating of hotels, apartment houses, office buildings by means of city-wide thermal loop</td>
</tr>
<tr>
<td>HAGEN</td>
<td>1967</td>
<td>480</td>
<td>203 381</td>
<td>Saturated steam converted into pressurized hot water for heating large outdoor municipal swimming pool and district heating of new Woodlands Housing Development and Old Folks Homes</td>
</tr>
<tr>
<td>OFFENBACH</td>
<td>1969</td>
<td>790 (1,060)(2)</td>
<td>228 500</td>
<td>Superheated steam for electrical power generation for in plant use and conversion to pressurized hot water for district heating of new suburb inclusive of housing developments, schools, shopping centers and churches</td>
</tr>
<tr>
<td>BOTLEK</td>
<td>1970/71</td>
<td>3,200</td>
<td>412 580</td>
<td>Superheated steam for electrical power generation and distillation of river water to supply feedwater to large petrochemical facilities</td>
</tr>
<tr>
<td>GBERHAUSEN</td>
<td>1972</td>
<td>1,740</td>
<td>996 977</td>
<td>Superheated steam for electrical power generation and district heat for two large manufacturing firms and municipal stadium</td>
</tr>
<tr>
<td>KREFELD</td>
<td>1974</td>
<td>650 (1,100)(2)</td>
<td>368 707</td>
<td>Superheated steam for electrical power generation to supply electrical needs of large municipal sewage treatment plant, accomplish sludge disposal and provide district heating for industrial park</td>
</tr>
<tr>
<td>GOEPPINGEN</td>
<td>1975</td>
<td>630 (950)(2)</td>
<td>555 770</td>
<td>Superheated steam for electrical power generation for in plant use and conversion to pressurized hot water for district heating of large regional medical complex and housing development</td>
</tr>
<tr>
<td>WUPPERTAL</td>
<td>1975</td>
<td>1,600 (2,000)(2)</td>
<td>412 662</td>
<td>Superheated steam for high performance electrical power plant with condensation turbines to supply municipal grid with 40 MW</td>
</tr>
<tr>
<td>BREMEN</td>
<td>1969/77</td>
<td>1,720</td>
<td>299 419</td>
<td>Saturated steam for conversion to pressurized hot water to supply large State University complex with energy for heating and air conditioning</td>
</tr>
<tr>
<td>HAMELN</td>
<td>1977</td>
<td>260</td>
<td>711 842</td>
<td>Fitted onto existing electrical power plant to generate superheated steam for electrical power production by utility company</td>
</tr>
</tbody>
</table>

Notes: (1) Design conditions as listed by manufacturer  
(2) Ultimate capacity upon plant expansion
tion, provides boiler feedwater, which is manufactured in its stills from seawater, for sale to industrial clients.

When discussing refuse power, it needs to be pointed out that not all plants which utilize this technology are equipped with water-walls; that is, the lining of the combustion chamber itself with membrane walls for the circulation of boiler water. The older and smaller plants in particular were often not equipped with water-walls; instead, they were simply provided with a refractory liner. Steam production was limited to more conventional boiler arrangements above the combustion chamber. Today, water-walls are preferred even for smaller plants, largely to avoid slagging associated with excessive combustion temperatures, which result from the greatly increased energy content, as previously mentioned, and for increased specific steam production (lb steam/lb waste). To a lesser extent, water-walls help to minimize formation of nitric oxides.

DESCRIPTION OF THE DUESSELDORF REFUSE POWER PLANT

Figure 2 shows the layout of the Flingern RPP in its present configuration, and Table 4 describes the major equipment installed. Located in a mixed residential and commercial neighborhood, it contains five major facilities on a 7.2 acre plot (2.91 \times 10^4 m^2): the refuse storage bunker, the boiler house, the gas cleaning facility, the ash processing building, and the administration building. The boiler house, with five (present) to six (ultimate) parallel processing lines, has the present design capacity to process 1400 ton/day (508,000 ton/year), (1.27 \times 10^6 kg/day), (4.61 \times 10^6 kg/year) of refuse and to generate 2900 ton/day (2.63 \times 10^6 kg/day), 1,060,000 ton/year (9.62 \times 10^8 kg/year), 242,000 lb/hr/average (1.10 \times 10^5 kg/h) of superheated steam. Actual processing and generating rates are lower and reflect the realities of operating conditions, such as waste logistics and equipment availability, which are discussed in subsequent sections.

This plant permanently employs 83 people and handles 700 to 800 vehicles of varying descriptions during a typical day shift. Traffic enters from the main road and is then rotated in a counter-clockwise fashion around the five major facilities, past the scale house to the tipping area. After discharging their wastes, the vehicles exit on the main road near the point of entry.

Although this plant has met all environmental guidelines in the past, there are now new requirements which were promulgated by the German Federal Environmental Protection Agency (EPA) in 1974 to reflect changes in refuse composition and added concern for air quality in industrial complexes next to already crowded population centers. As a result, the gas cleaning facility is scheduled for major expansion and upgrading during 1979 to bring the plant in compliance with the new Technische Anleitung Luft, known as TA Luft 74 [3]. Dry scrubbers, in addition to existing precipitators, will be required as part of this upgrading.

Plant output leaves the plant in the form of high and intermediate pressure steam lines at the south side, which straddle the rail line and interconnect the Flingern RPP with the Flingern EPS, approximately 2300 ft away (7.01 \times 10^2 m).

Recovered ferrous scrap and ash processed for construction use are removed by private contractors from the ash processing building.

Figure 3 presents a sectional view of the Flingern RPP. Packer trucks, shown on the left, discharge their wastes into rotary pusher beds. By hydraulic action, these pushers eliminate the angle of repose problem associated with conventional tipping floors, thus permitting the use of a shallow bottom bunker. From there, cranes lift and place the refuse into feed hoppers, from which ram feeders charge it onto the roller grate system. Each roller has its own variable speed drive and variable delivery air supply to ensure optimum conditions for controlled combustion. In this manner, a variety of wastes can be received, dried and mixed, resulting in a high degree of burnout for all of them, together with efficient heat release and low pollution loads.

In this context, it is worthy of note that Units 1 to 4 use seven rollers, while Unit 5 uses only six rollers. This simplification was made possible by the reduced moisture content and increased calorific value of refuse in recent years, requiring less retention time in the combustion chamber. The boilers do not reflect the latest state-of-the-art design, but they have been sufficiently modified for reliable and efficient operation. They are of the single drum, natural circulation type, with one pass containing the radiation shaft and superheater, and another pass containing the convection section and economizer.* Plant steaming rates are now limited by the boiler design criteria which were set many

* Units 1 to 4, which are of the counter-flow type; that is, refuse and flue gases move in opposite directions. Unit 5 has a four-pass boiler design, and uses parallel flow; that is, refuse and flue gases move in the same direction.
1. Entrance and Exit
2. Administration Building, Work Shop, Offices
3. Vehicle Turning Area
4. Bulky Waste Shear
5. Tipping Area
6. Refuse Storage Bunker with Charge Cranes and Feed Hoppers
7. Boiler House, Boilers #1–6
8. Weight Scales
9. Steam and Condensate Lines Connecting to Flingern Power Plant
10. Control Room
11. Information Center
12. Ash Processing Building
13. Loading Hoppers for Processed Ash
14. Scrap Baling Presses
15. Exhaust Fans and Stack
16. Excess Ash Storage Bunker
17. RG Type Silencers
18. Parking Lot
19. Sportsfield – Area for Future Plant Expansion
20. Fuel Oil Tank
21. Circulation Pumps
22. Feed Tank
23. Settling Tanks
24. Lime Storage Silos
25. Neutralization Tank
26. Electrostatic Precipitators
27. Bulky Waste Shredder

FIG. 2 LAYOUT OF FLINGERN REFUSE POWER PLANT
TABLE 4 1400 STPD REFUSE POWER PLANT: PLANT DESCRIPTION

Site Location-------------Mixed Residential and Commercial Neighborhoods in Large City--Capital of the State of North Rhine Westphalia in the FRG

Space Requirements-------Structures: 75,300 sq. ft., or 1.7 acres
Roads: 170,400 sq. ft., or 3.5 acres
Landscaping: 86,100 sq. ft., or 2.0 acres
Total Plot: 331,800 sq. ft., or 7.2 acres

Technology----------------Duesseldorf Roller Grate System with High Performance Steam Boiler Supplied by VKW/German Babcock

Construction, Phase I-----4 Processing Lines @ 11 st/h Refuse and 22 st/h Steam with 7 Rollers @ 5 ft. X 10 ft. L and 3-6 RPH

Plant Design Capacities---4 X 11 X 24 X 365 = 385,000 STPY Refuse
4 X 22 X 24 X 365 = 771,000 STPY Steam
Specific Steaming Rate = 2.00 ST of Steam/ST of Refuse*
Cost: $13.6 Million in 1965, Including 2 Electrostatic Precipitators, Buildings, Roads, and Other Site Development

Construction, Phase II----1 Processing Line @ 14 st/h Refuse and 33 st/h Steam with 6 Rollers @ 5 ft. X 10 ft. L and 3-6 RPH

Plant Design Capacities---[(4 X 11) + (1 X 14)] X 24 X 365 = 508,000 STPY Refuse
or 1,390 STPD
[(4 X 22) + (1 X 33)] X 24 X 365 = 1,060,000 STPY Steam
or 2,900 STPD
Specific Steaming Rate = 2.09 ST of Steam/ST of Refuse
Cost: $4.6 Million in 1972, Including 1 Electrostatic Precipitator, 1 Shredder, Buildings, and Associated Sitework

Ultimate Plant Capacity---6 Processing Lines for 630,000 STPY Refuse and 1,350,000 STPY Steam

Air Pollution Controls----3 Electrostatic Precipitators with 99.7% Particulate Removal, 328 ft. Stack

Capital Costs-------------$18.2 Million Actual in 1965-1972, Escalated to $42 Million in 1977, or $30,200/STPD Installed Capacity

Traffic Volume----------700-800 Vehicles During 8-Hour Period (Day Shift)

Employment-------------83 People (Day Shift Plus 4 Operating Shifts Including Reserves)

* Was initially 1.60 before upgrading of the economizers in 1971
1. Tipping Bays with Rotary Push Feeders
2. Refuse Storage Bunker, 371,000 cubic foot capacity
3. Refuse Charging Cranes, 11 ST carrying capacity
4. Control Room for Crane Operator
5. Reserve Charging Crane and Repair Platform
6. Feed Hoppers for Refuse Fired Boiler
7. Refuse Fired Grate-Boiler Combination
7a. Roller Grate System “Dusseldorf” for Controlled Combustion of Mixed Municipal Refuse
7b. First Pass of Boiler with Superheater
7c. Second Pass of Boiler with Steam Generator and Economizer
8. Feedwater Storage Tank
9. Feedwater Entrance at Boiler
10. High-Pressure Steam Exit at Boiler
11. Fluegas Exit at Boiler
12. Two Field Electrostatic Precipitator
13. Induced Draft Fan
14. Exhaust Stack, 328 ft high
15. Riddling Hoppers
16. Quench Tank with Ash Extractor
17. Ash Conveyor to Ash Processing Building
18. Control Room

FIG. 3 SECTIONAL VIEW OF FLINGERN REFUSE POWER PLANT
(Units #1 – #4, Phase I)
FLOW OF ENERGY AND MATERIALS

In previous sections, the layout and the equipment of the Flingern RPP were described. It is the purpose of this section to delineate major inputs to and outputs from the plant. Table 5 lists inputs and outputs on an annual basis for the 1966 to 1976 period.

Since the plant receives return condensate from the Flingern EPS and produces quench water from its own wells, refuse and electricity remain the only major inputs. Population served has declined only slightly, whereas the amount of refuse processed actually increased primarily due to four factors:

1. Increased per capita generation rate.
2. The learning curve of the operating crew.
3. Equipment modifications.
4. The addition of the fifth processing line in 1972.

During the design of the plant, it was decided, because of local conditions which appeared highly favorable, not to install plant-owned turbo-alternators and, instead, to purchase the electricity from Stadtwerke A.G., the recipient of the plant's steam output. Electrical purchases increased sharply in 1972 when the fifth processing line was added and other equipment, such as fans and pumps, was replaced by equipment of higher capacity. A second jump in electrical purchases occurred in 1973, when a shredder was put into operation for an acceleration in the size reduction of certain bulky wastes. After this, the RPP's electrical consumption levelled off at approximately 14,180 MWh/year, or 1.62 MW average level. In 1976, the electric bill amounted to approximately $0.7 million, which surpasses by far the annualized capital and operating costs of turbo-alternators and switch gear in this size category. Therefore, in retrospect, the decision made during the design of the plant to purchase electricity would need to be reevaluated if a new plant was to be built in Duesseldorf today. In addition, refuse power plants run continuously, and for the better part draw electrical power at steady levels of consumption (except for the processing of bulky wastes). Therefore, in view of the modern trend towards time of day metering, they become base loaders in a utility sense and should be given preferential electrical rates by the public utility companies, which does not appear to be the case in Duesseldorf. This should be above and beyond the special tariff already granted by the utility to its large energy users.

The output data are grouped as energy recovery, metal recovery, and ash recovery. Energy recovery and steam production increased because of the increase in refuse processing, but also to a much larger extent due to the increased heating value of the refuse fired. As a result, the specific steam production rate of 1.59 in 1966 increased to 2.07 tons of steam per ton of refuse in 1976.

Due to the lack of homogeneity of refuse as a fuel, it is difficult to maintain the supplied steam at steady temperature and pressure conditions. Because of this, the terms "supply ton" and "accounting ton" were created, where the first applies to the amount of steam actually delivered, and the second adjusts this figure to the amount which would be delivered if predetermined pressure and temperature conditions could be maintained constantly.

Metal recovery by means of magnetic separation from the processing of residue in 1975 can be cal-

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The output data are grouped as energy recovery, metal recovery, and ash recovery. Energy recovery and steam production increased because of the increase in refuse processing, but also to a much larger extent due to the increased heating value of the refuse fired. As a result, the specific steam production rate of 1.59 in 1966 increased to 2.07 tons of steam per ton of refuse in 1976.

Due to the lack of homogeneity of refuse as a fuel, it is difficult to maintain the supplied steam at steady temperature and pressure conditions. Because of this, the terms "supply ton" and "accounting ton" were created, where the first applies to the amount of steam actually delivered, and the second adjusts this figure to the amount which would be delivered if predetermined pressure and temperature conditions could be maintained constantly.

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The output data are grouped as energy recovery, metal recovery, and ash recovery. Energy recovery and steam production increased because of the increase in refuse processing, but also to a much larger extent due to the increased heating value of the refuse fired. As a result, the specific steam production rate of 1.59 in 1966 increased to 2.07 tons of steam per ton of refuse in 1976.

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Metal recovery by means of magnetic separation from the processing of residue in 1975 can be cal-
TABLE 5 1400 STPD REFUSE POWER PLANT\(^{(1)}\): ANNUAL FLOW OF ENERGY AND MATERIALS\(^{(2)}\)(\(^{(3)}\))(IN ST X 1000\(^{(4)}\))

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>1966</td>
<td>224</td>
<td>7,927</td>
<td>356</td>
<td>8.10</td>
<td>8.10</td>
<td>88.6</td>
<td>+77.0</td>
<td>58.1</td>
</tr>
<tr>
<td>67</td>
<td>260</td>
<td>8,315</td>
<td>408</td>
<td>9.60</td>
<td>0.35</td>
<td>9.95</td>
<td>108.7</td>
<td>97.1</td>
</tr>
<tr>
<td>68</td>
<td>282</td>
<td>8,738</td>
<td>470</td>
<td>9.36</td>
<td>0.42</td>
<td>9.78</td>
<td>116.3</td>
<td>95.5</td>
</tr>
<tr>
<td>69</td>
<td>290</td>
<td>9,242</td>
<td>495</td>
<td>9.38</td>
<td>0.57</td>
<td>9.95</td>
<td>117.4</td>
<td>98.9</td>
</tr>
<tr>
<td>70</td>
<td>290</td>
<td>9,477</td>
<td>512</td>
<td>9.09</td>
<td>0.74</td>
<td>9.83</td>
<td>119.0</td>
<td>98.0</td>
</tr>
<tr>
<td>71</td>
<td>267</td>
<td>3,420</td>
<td>500</td>
<td>8.90</td>
<td>0.95</td>
<td>9.85</td>
<td>97.5</td>
<td>86.9</td>
</tr>
<tr>
<td>72(^{(9)})</td>
<td>295</td>
<td>12,210</td>
<td>567</td>
<td>9.24</td>
<td>0.97</td>
<td>10.21</td>
<td>101.4</td>
<td>88.4</td>
</tr>
<tr>
<td>73</td>
<td>318</td>
<td>13,955</td>
<td>593</td>
<td>10.32</td>
<td>0.62</td>
<td>10.94</td>
<td>114.2</td>
<td>97.1</td>
</tr>
<tr>
<td>74</td>
<td>328</td>
<td>14,143</td>
<td>572</td>
<td>9.95</td>
<td>0.56</td>
<td>10.51</td>
<td>114.9</td>
<td>89.0</td>
</tr>
<tr>
<td>75</td>
<td>327</td>
<td>14,107</td>
<td>650</td>
<td>10.10</td>
<td>0.61</td>
<td>10.71</td>
<td>116.2</td>
<td>98.4</td>
</tr>
<tr>
<td>76</td>
<td>315</td>
<td>14,521</td>
<td>652</td>
<td>9.39</td>
<td>0.59</td>
<td>9.98</td>
<td>107.4</td>
<td>85.8</td>
</tr>
<tr>
<td>Totals</td>
<td>3,196</td>
<td>122,057</td>
<td>5,775</td>
<td>103.43</td>
<td>6.38</td>
<td>109.81</td>
<td>1,201.6</td>
<td>1,023.9</td>
</tr>
<tr>
<td>Averages</td>
<td>291</td>
<td>11,096</td>
<td>525</td>
<td>9.40</td>
<td>0.58</td>
<td>9.98</td>
<td>109.2</td>
<td>93.1</td>
</tr>
<tr>
<td>11-Year Changes</td>
<td>+ 40.2%</td>
<td>+ 83.2%</td>
<td>+ 83.1%</td>
<td>+ 89.9%</td>
<td>+ 15.9%</td>
<td>+ 68.6%</td>
<td>+ 23.2%</td>
<td>+ 21.2%</td>
</tr>
</tbody>
</table>

Notes:
(1) Installed processing capacity in short tons of mixed municipal refuse per day when operating continuously
(2) 1.0 MT = 1.1 ST was used for conversion
(3) Data Base: EDP summaries consolidated into annual report which is submitted by operator to the owner in June each year
(4) Except for electricity which is expressed in MWh
(5) Fully corrected tonnages of combustible solid waste actually processed. Total tonnages collected and delivered are generally 6 - 20% higher because insufficient plant capacity necessitates bypassing to landfill site
(6) Because of local conditions, it was decided to purchase electricity for in-plant use rather than to install own turbo-alternators
(7) Tons of steam supplied at conditions of actual pressure and temperature, i.e. the "supply ton"
(8) Tons of steam adjusted to reference conditions, i.e. the "accounting ton"
(9) Fifth processing line installed, started operating late in August
(10) Recession affects construction industry
ulated at an efficiency of about 62 percent, when using the ferrous concentration of 5.1 percent found by the visual analysis of residential refuse samples. However, it is the operator’s contention that magnetic separation is much more efficient; that is, most likely close to 90 percent because the ferrous content of the refuse actually processed in the RPP is about 3.5 percent and not 5.1 percent due to the admixture of sweeping, industrial and commercial wastes, which have lower ferrous contents. Refuse composition is further explained in the following section. On the whole, scrap sales were largely affected by fluctuations in the amount of white goods collected, such as household appliances.

While raw ash recovery remained steady between 110,000 (9.98 x 10^7 kg/year) and 120,000 ton/year (1.09 x 10^9 kg/year), ash processing fluctuated and produced two peaks, one in 1970 and the other in 1973. Of these two, the 1970 peak is particularly significant in that a record tonnage, or 93.4 percent of production, was sold to the construction industry. Thereafter, ash sales showed a steady decline which can be explained best by the effects of a continued recession.

**WASTE CLASSIFICATION AND COMPOSITION**

The Flingern RPP receives a variety of wastes, which attests to the reliability and versatility of the system. As a result, few constraints, if any, are imposed on the Department of Sanitation and the citizens of Duesseldorf, eliminating the need for source segregation. In fact, the Flingern RPP responds to the true needs of the Department of Sanitation in accepting the following six types of waste: residential, industrial and commercial, bulky wastes, yard waste and sweepings, dirt with oil contamination, and automobile tires.

Table 6 lists these classifications for a typical operating year in which a total of 328,000 tons (2.16 x 10^8 kg) were processed. Of this total, 93.2 percent, or the vast majority, was processed in the “as received” condition, mostly dumped by packer trucks. The remainder was put through the shear or the shredder for size reduction to assure better mixing of the feed and a complete burnout at average retention time on the grates. Table 6 also introduces the concept of a variable tipping fee which, although considered controversial in some quarters, relates to the amount of handling and energy consumption involved in the accommodation of widely diverse types of wastes. For example, automobile tires need to be sheared and mixed with residential refuse. Likewise, bulky wastes need to be shredded and mixed in.

Since shears and shredders are relatively high in personnel, capital, maintenance and energy costs, a proportionally higher tipping fee is charged. The large capacity for bulky waste reduction at the Flingern RPP is provided mainly to accommodate the needs of certain commercial and industrial customers.

Industrial and commercial wastes are delivered by private vehicles which in size and type vary from a 1/2-ton trailer to a 10-ton truck (net loads). This sort of delivery complicates traffic patterns and requires additional yard and administrative work. Again, a slightly higher tipping fee is charged in this classification as compared by residential.

Duesseldorf, being located on both sides of the Rhine River, encounters a number of inevitable oil spills as a result of heavy river traffic with fuel barges, although a larger contribution comes from other sources involving traffic accidents with tank trucks or leakage from old fuel oil storage tanks in space heating systems. Mopping up of such spills or leakage is accomplished by rolling up the sand with the oil and trucking it to the Flingern RPP for disposal on the grates. Because this material is largely inert and has a negative effect on the steam production, an extra high tipping fee is charged. As a consequence of the leakage or dumping of hazardous substances, fish kills occur occasionally in the Rhine River, in which case the cadavers are also brought to the Flingern RPP for disposal.

Finally, residential refuse is collected by the sanitation departments of Duesseldorf and its neighboring municipalities. Containers of different sizes and shapes are rented to homeowners and business operators on a monthly or quarter-annual basis so that there is a direct charge for the amount of wastes generated. These containers are periodically cleaned with steam withdrawn from the RPP to assure the highest standards of cleanliness and hygiene. This approach is simple and has worked well in Duesseldorf and its environs; it obviates the need for levying ultimate disposal charges against a myriad of manufacturers of goods ranging from toys to bottles, a concept that has been proposed in the United States (the so-called “Penney-A-Pound System”).

Accurate descriptions of waste compositions are hard to come by, although the city employs the full time services of a refuse sampler. Table 7 shows the results of an annual sampling program of residential refuse as it is received in various containers. This analysis should be used with due caution, because residential refuse accounts for only 67 percent of the annual total processed. Industrial and com-
<table>
<thead>
<tr>
<th>WASTE CLASSIFICATION</th>
<th>ANNUAL THROUGHPUT</th>
<th>TIPPING FEES</th>
<th>INCOME</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ST</td>
<td>% OF TOTAL THROUGHPUT</td>
<td>$/ST</td>
</tr>
<tr>
<td>1. Residential Refuse (Burned as Received)</td>
<td>184,219</td>
<td>56.2</td>
<td>$9.34(1)</td>
</tr>
<tr>
<td>1a. Collection by Host City</td>
<td>35,783</td>
<td>10.9</td>
<td>$9.34(2)</td>
</tr>
<tr>
<td>1b. Collection by Outside Municipalities</td>
<td>220,002</td>
<td>67.1</td>
<td>9.34</td>
</tr>
<tr>
<td>2. Industrial &amp; Commercial Refuse (Burned as Received)</td>
<td>73,849</td>
<td>22.5</td>
<td>10.77</td>
</tr>
<tr>
<td>3. Bulky Wastes (Burned after Shredding and Mixing)</td>
<td>20,742</td>
<td>6.3</td>
<td>12.57</td>
</tr>
<tr>
<td>4. Yardwaste &amp; Sweepings (Burned as Received)</td>
<td>10,131</td>
<td>3.1</td>
<td>N.C.(3)</td>
</tr>
<tr>
<td>5. Dirt with Oil Contamination (Burned as Received)</td>
<td>2,434</td>
<td>0.7</td>
<td>18.67</td>
</tr>
<tr>
<td>6. Automobile Tires (Burned after Shearing and Mixing)</td>
<td>844</td>
<td>0.3</td>
<td>14.72</td>
</tr>
<tr>
<td>TOTALS 1 - 6</td>
<td>328,002</td>
<td>100.0</td>
<td>9.66(4)</td>
</tr>
</tbody>
</table>

NOTES:

(1) Not a cash receipt, but an annual subsidy based on projected tipping fees and provided by the City to the budget of the Sanitation Department to cover the difference between revenues and expenses.

(2) Not a cash receipt but an annual disbursement based on projected tipping fees plus a backcharge for the cost of landfilling ash which is not sold to the construction industry.

(3) There is no charge for yardwaste and sweepings brought in by the Department of Sanitation.

(4) Average tipping fee for the total tonnage of wastes processed. From Table 10 it can be seen that only $8.93/ST would be required for budget balancing.

(5) In case revenues generated from the sale of energy and materials plus the collection of tipping fees exceed expenses, the resulting surplus will be used by the Department of Sanitation within its discretion to defray other expenses not necessarily related to refuse power plant operations, or it can be put in a reserve fund. Such a reserve fund is then carried over to the following year and may be used to alleviate the need for an increase in tipping fees due to rising expenses. From examination of Table 9, it can be seen that only $2,929,000 in tipping fees were required to balance the 1974 budget. The difference between $3,168,000 and $2,929,000 resulted in a $239,000 surplus which was carried over into the 1975 budget; and which, because of this, permitted continuation of the 1974 Tipping Fee Schedule shown above. In case of a budget deficit, a special hike in tipping fees not related to increased expenses would be required for compensation during the following year.
<table>
<thead>
<tr>
<th>Table 7: Refuse Characteristics in Europe and the United States</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Continent</strong></td>
</tr>
<tr>
<td><strong>Locality</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Type of Waste</strong></td>
</tr>
<tr>
<td><strong>Sample Year</strong></td>
</tr>
<tr>
<td><strong>Number of Samples</strong></td>
</tr>
<tr>
<td><strong>Materials Composition</strong></td>
</tr>
<tr>
<td><strong>1. Paper</strong></td>
</tr>
<tr>
<td><strong>2. Organics</strong></td>
</tr>
<tr>
<td><strong>3. Glass</strong></td>
</tr>
<tr>
<td><strong>4. Metals</strong></td>
</tr>
<tr>
<td><strong>Plastics</strong></td>
</tr>
<tr>
<td><strong>Rubber and Leather</strong></td>
</tr>
<tr>
<td><strong>Textiles</strong></td>
</tr>
<tr>
<td><strong>Combustible: Wood, Cardboard, etc.</strong></td>
</tr>
<tr>
<td><strong>Cardboard</strong></td>
</tr>
<tr>
<td><strong>Misc. (Fibers, Residues, etc.)</strong></td>
</tr>
<tr>
<td><strong>Water In-weight</strong></td>
</tr>
<tr>
<td><strong>Lower Heating Value</strong></td>
</tr>
<tr>
<td><strong>Higher Heating Value</strong></td>
</tr>
<tr>
<td><strong>Sources and Notes:</strong></td>
</tr>
</tbody>
</table>

**Sources and Notes:**

4. Landesamt für Umwelt und Raumordnung: "Studie über die Abfallwirtschaft in Nordrhein-Westfalen 1975".
5. Bundesanstalt für den Umweltschutz: "Deutsche Städtetätigkeit 1975".

**Note:** Values may be subject to error due to differences in methods and assumptions.
mercial refuse, accounting for 22 percent of the total and varying widely in composition, may significantly affect this analysis.

Table 7 also compares Duesseldorf refuse with that of other cities in Europe. While refuse composition and heat content are similar for Duesseldorf, Stuttgart, and Hamburg, there is a vast difference in Stockholm. The latter, in addition to a high plastics content, has an inordinately high amount of paper and cardboard resulting in a very high heating value.

In order to put European experience in perspective with regard to its application in the United States, Table 7 was extended to include a description of refuse characteristics in the United States. Close inspection of this table clearly reveals the striking similarity of Stockholm refuse to United States refuse, an observation which comes as no surprise when one takes note of several recent studies which have found that the standard of living in Sweden is comparable to that of the United States [5].

PRICES FOR ENERGY AND MATERIALS

Although most economists concede that the Federal Republic of Germany has been more successful than most countries in stemming the effects of inflation, there are significant price movements in most categories investigated in the last eleven years.

Table 8 presents annual price averages as they affected the Flingern RPP, together with statistical indices for equipment and services, to afford a better basis of comparison.

Tipping fees remained steadily within the $4.50 to $6.00/short ton band (5 mills to 6.6 mills/kg) from 1966 to 1972. Thereafter, two significant increases occurred, one in 1973 and the other in 1976. The first followed fresh capital investments for plant upgrading and expansion. The second reflected an acceleration in the average depreciation rate, which was reduced from 22 years to 18 years in order to conform with industry standards. Additional increases were forced by the disproportionately high rises in hourly wages.

An increase of 42 percent in the unit price of electricity showed the lowest gain of any category, largely a result of the Stadtwerke A.G. system operating on a large scale and with a suitable mix of equipment and fuels. In resonance with West Germany's general practice of deriving about 44 percent of its publicly sold electricity from coal*, the Flingern EPS also used coal in significant quantities**.

In 1976, the Flingern RPP paid an average of 26.1 mills/kWh for the purchase of 14,521 MWh from the Flingern EPS. This represents an attractive wholesale price, because systems-wide sales by Stadtwerke A.G. are reported at $146.4 million for 3.011 million MWh, or an average of 48.6 mills/kWh (retail to wholesale ratio = 48.6/26.1 = 1.86) [6].

Steam prices, with a gain of 95 percent, nearly doubled; however, these prices do not necessarily reflect real earnings by Stadtwerke A.G. on the combined sales of electricity and district heat, because its new district heating network was installed only after the initial contract was signed between the RPP and the EPS for the long-term purchase of steam. Therefore, the steam generated by the RPP does not relate directly to the energy market in which both electricity and heat are being sold as the result of the increased net energy efficiency of cogeneration.

Actually, the main escalator in this category is the cost of coal, since coal derived steam at predetermined pressure and temperature is used as the reference point. Perhaps the RPP should be awarded an incentive clause which would be based on the amount of conventional fuel saved by the EPS cogeneration system as it exists today and expands tomorrow.

In 1976, the Flingern RPP paid an average of $2.79/1000 lb (6.2 mills/kg) for the sale of 1.24 billion lb (5.62 × 10^8 kg) of steam (using the accounting ton), which could be interpreted as a wholesale price. Undoubtedly, the Flingern EPS and Stadtwerke A.G. were paid more by their energy customers because of the capital investment and the operating and maintenance expenses associated with the district heating network [6]. By utilizing published Stadtwerke data for systems-wide sales of electricity and heat, the retail value of RPP steam can be estimated at $5.27/1000 lb, (11.6 mills/kg), a figure which is more in line with the performance of United States district heating networks (retail to wholesale ratio = 5.27/2.79 = 1.89). The International District Heating Association (IDHA) reported

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* In 1976, the public utilities used 24 percent bituminous and 20 percent lignite coal for their electrical power production.

** In 1976, the Flingern EPS fired 83 percent bituminous and 17 percent lignite coal based on SKE's (Steinkohleenheit; that is, the thermal energy content of bituminous coal based on a heating value of 7000 kcal/kg), (2.93 X 10^6 kJ/kg).
<table>
<thead>
<tr>
<th>Plant Operating</th>
<th>Electricity Prices</th>
<th>Steam Prices</th>
<th>Scrap Prices</th>
<th>Ash Prices</th>
<th>Equipment</th>
<th>Structures Living Wages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>$/ST (4)</td>
<td>$/1,000 lb (6)</td>
<td>$/ST (5)</td>
<td>$/ST (7)</td>
<td>$/ST (8)</td>
<td>$/ST (10)</td>
</tr>
<tr>
<td></td>
<td>mWh/KWh</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1966</td>
<td>5.42</td>
<td>2.87</td>
<td>1.44</td>
<td>15.55</td>
<td>0.16</td>
<td>23.82</td>
</tr>
<tr>
<td>1967</td>
<td>4.55</td>
<td>1.89</td>
<td>1.44</td>
<td>17.65</td>
<td>0.15</td>
<td>27.11</td>
</tr>
<tr>
<td>1968</td>
<td>4.76</td>
<td>1.86</td>
<td>1.44</td>
<td>17.85</td>
<td>0.15</td>
<td>30.45</td>
</tr>
<tr>
<td>1969</td>
<td>4.83</td>
<td>1.72</td>
<td>1.44</td>
<td>23.37</td>
<td>0.15</td>
<td>35.15</td>
</tr>
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<td>1970</td>
<td>4.98</td>
<td>1.75</td>
<td>1.44</td>
<td>23.06</td>
<td>0.15</td>
<td>37.01</td>
</tr>
<tr>
<td>1971</td>
<td>5.96</td>
<td>1.84</td>
<td>1.57</td>
<td>18.92</td>
<td>0.14</td>
<td>26.39</td>
</tr>
<tr>
<td>1972</td>
<td>5.98</td>
<td>1.84</td>
<td>1.65</td>
<td>15.21</td>
<td>0.14</td>
<td>24.69</td>
</tr>
<tr>
<td>1973</td>
<td>7.96</td>
<td>1.89</td>
<td>1.72</td>
<td>20.70</td>
<td>0.17</td>
<td>29.43</td>
</tr>
<tr>
<td>1974(12)</td>
<td>8.93</td>
<td>2.10</td>
<td>1.80</td>
<td>27.71</td>
<td>0.17</td>
<td>35.35</td>
</tr>
<tr>
<td>1975</td>
<td>9.15</td>
<td>2.48</td>
<td>1.90</td>
<td>30.42</td>
<td>0.16</td>
<td>38.54</td>
</tr>
<tr>
<td>1976</td>
<td>11.01</td>
<td>26.1</td>
<td>2.79</td>
<td>27.39</td>
<td>0.25</td>
<td>26.54</td>
</tr>
<tr>
<td>Averages</td>
<td>6.45</td>
<td>19.9</td>
<td>35.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td>+103%</td>
<td>+42%</td>
<td>+95%</td>
<td>+94%</td>
<td>+36%</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Installed processing capacity in short tons of mixed municipal refuse per day when operating continuously.
2. 1970 = 0.395 U.S. $ and 1 M$ = 1.1 ST were used for conversion.
5. Prices paid for clean, mixed and source segregated paper exclusive VAT tax. For paper recovered from municipal refuse, if it is saleable at all, there are substantial deducts.
7. U.S. $ per 1,000 lb of steam sold and adjusted to reference conditions, i.e., the "accounting ton" and not the "supply ton".
8. Steam boilers and tanks.
10. Annual changes are extrapolated by assuming linear growth in costs.
for 1976 an average of $4.14 (9.1 mills/kg), [a minimum of $1.16 (2.6 mills/kg) and a maximum of $8.60 (19 mills/kg)] in gross revenues for the sale of 1000 lb of steam on a total volume of 150 billion lb (6.80 x 10\(^{10}\) kg) sold by 72 member companies throughout the United States and Canada [7].

Scrap prices are subject to yearly public bidding by private contractors. Since the scrap market in the FRG shows fluctuations similar to those in the United States, the general increase of 76 percent is mainly due to the increased cost of energy to the steel industry and the unusually clean scrap produced by the Flimgern RPP.

Ash prices are somewhat erratic and only started to move upward during the last three years. Ash prices reflect the well-being of the construction industry, which is also evidenced by the fact that the amount of ash sold varies widely and has declined during the last three years.

Paper prices were included to afford a comparison between energy recovery and materials recycling. Much like other fiber-rich countries such as the United States, the FRG experienced unstable paper prices. With the exception of 1974, the year of the oil crisis and its concomitant market perturbations, the price for clean mixed Grade B-12 paper declined by about 11 percent. Prices for dirty and mixed grade paper are not available, because on one hand such paper cannot be sold in most years, and on the other hand there are no full-scale materials recovery plants known to be operating in the FRG. Even in the years that such scrap paper has been sold, according to the Bundesverband der Papier Rohstoffe, its price was substantially below that of Grade B-12. Furthermore, it can be shown that, during 1976, a ton of dirty paper fired in the RPP would earn approximately $28.00/ton (31 mills/kg) as steam versus less than $26.00/ton (29 mills/kg) as dirty scrap, provided that a suitable buyer for the scrap could be found.

In the United States, several paper companies have stated that their forests are not yet managed in a manner which would produce an optimum yield in tons of fiber per acre of forestry land cultivated. Improvements in pulp processing technology, such as frequency tuning of mechanical pulping, may result in substantial energy savings, which would further tend to reduce the value of scrap [8].

As a final point, it should be emphasized that in countries with proper forestry management, fibers are a renewable resource, whereas fossil fuels are not. The above considerations strongly mitigate in favor of energy recovery over paper recovery.

**INCOME FROM THE SALE OF SERVICES AND PRODUCTS**

From inspection of Table 9, it can be gleaned that operation of the Flimgern RPP caused a steady rise in total annual income, from $2.3 million to $7.2 million, during the 11-year observation period. This total income is derived from the combination of two major income categories: tipping fees and resource recovery. In the first category, income from tipping fee collections increased by 185 percent as a result of both increased plant throughput and increased tipping fees. In the second category, a strong and steady rise in income earned from the sale of energy was the principal individual contributor. This development occurred in spite of a concurrent 10 percent loss in the population served, and was made possible because of the tandem increases in refuse energy value and refuse generation rate, both key factors which were previously cited. Income from the sale of energy soared by 269 percent, showing a spectacular rise which overshadowed all other developments, again attesting to the wise choice made by the city fathers in having opted, in 1962, for energy recovery and its optimization. However, it is not equally clear as to why they did not opt, in 1970, for the installation of two new units of the larger type instead of just one, since bypassing of combustible municipal solid waste has been a reality in Duesseldorf since that time (see Table 1). At this point, one is tempted to speculate as to how much more the income picture could have been affected if the plant would have been equipped with three grates at 16 ton/hr capacity each (1.45 x 10\(^4\) kg/h) in 1965 and with an additional grate at 16 ton/hr (1.45 x 10\(^4\) kg/h) in 1972. This would have resulted in plant design capacities of 420,000 ton/year (3.81 x 10\(^8\) kg/year) and 560,000 ton/year (5.08 x 10\(^8\) kg/year) respectively, which, given an average equipment availability factor of 0.75 and an average plant capacity factor of 0.75, could have virtually eliminated the bypassing of refuse. This approach could have been applied to both the 1966 to 1967 and the 1972 to 1976 periods, resulting in increased revenues.

Perhaps conservatism dominated the thinking of the design engineers responsible for the original layout of the Flimgern RPP. First, the Flimgern pilot plant had a processing rate of only 11 ton/hr (9.98 x 10\(^3\) kg/h); and second, only one larger system of the Duesseldorf type had been designed during the same period of time, which was a 22 ton/hr

\*Resource recovery includes energy in addition to scrap and ash, mainly because, in the case of Duesseldorf, refuse power conserves fossil fuel, a nonrenewable resource.
<table>
<thead>
<tr>
<th>Plant Year</th>
<th>Tipping Fees Disposal (3)</th>
<th>Energy Sales</th>
<th>Scrap Sales</th>
<th>Ash Sales</th>
<th>Resource Recovery (4) Total Income</th>
<th>Ratio Resource Recovery to Total Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>1,213</td>
<td>940</td>
<td>126</td>
<td>9.6</td>
<td>1,075</td>
<td>2,288</td>
</tr>
<tr>
<td>67</td>
<td>1,181</td>
<td>1,129</td>
<td>176</td>
<td>13.4</td>
<td>1,318</td>
<td>2,499</td>
</tr>
<tr>
<td>68</td>
<td>1,345</td>
<td>1,249</td>
<td>233</td>
<td>14.3</td>
<td>1,497</td>
<td>2,842</td>
</tr>
<tr>
<td>69</td>
<td>1,401</td>
<td>1,337</td>
<td>232</td>
<td>13.2</td>
<td>1,583</td>
<td>2,984</td>
</tr>
<tr>
<td>70</td>
<td>1,292</td>
<td>1,481</td>
<td>227</td>
<td>14.5</td>
<td>1,722</td>
<td>3,014</td>
</tr>
<tr>
<td>71</td>
<td>1,593</td>
<td>1,548</td>
<td>186</td>
<td>11.5</td>
<td>1,746</td>
<td>3,339</td>
</tr>
<tr>
<td>72</td>
<td>1,753</td>
<td>1,838</td>
<td>155</td>
<td>10.9</td>
<td>2,004</td>
<td>3,758</td>
</tr>
<tr>
<td>73</td>
<td>2,528</td>
<td>2,029</td>
<td>226</td>
<td>12.2</td>
<td>2,267</td>
<td>4,795</td>
</tr>
<tr>
<td>74(6)</td>
<td>2,929</td>
<td>2,386</td>
<td>291</td>
<td>13.7</td>
<td>2,691</td>
<td>5,620</td>
</tr>
<tr>
<td>75(7)</td>
<td>2,993</td>
<td>3,209</td>
<td>390</td>
<td>19.2</td>
<td>3,618</td>
<td>6,612</td>
</tr>
<tr>
<td>76</td>
<td>3,467</td>
<td>3,470</td>
<td>273</td>
<td>8.7</td>
<td>3,752</td>
<td>7,219</td>
</tr>
<tr>
<td>Totals</td>
<td>21,695</td>
<td>20,616</td>
<td>2,515</td>
<td>141.2</td>
<td>23,273</td>
<td>44,970</td>
</tr>
<tr>
<td>Averages</td>
<td>1,972</td>
<td>1,874</td>
<td>229</td>
<td>12.8</td>
<td>2,116</td>
<td>4,088</td>
</tr>
<tr>
<td>11-Year Changes</td>
<td>+ 185%</td>
<td>+ 269%</td>
<td>+ 117%</td>
<td>- 9%</td>
<td>+ 249%</td>
<td>+ 216%</td>
</tr>
</tbody>
</table>

Notes:  
(1) Installed processing capacity in short tons of mixed municipal refuse per day when operating continuously  
(2) 1 DM = 0.395 US $ was used for conversion; no attempt was made to allow for inflation and/or fluctuations in the currency exchange rate  
(3) This source represents the composite of tipping fees actually charged to industrial and commercial users as well as neighboring municipalities. Also included in this composite is a subsidy provided by the city government which covers the difference between expenses and receipts. The city charges its residents a container rental fee which covers the total cost of refuse collection and disposal. The disposal portion of this fee essentially makes up the subsidy.  
(4) Income from resource recovery is the combination of energy, scrap, and ash sales  
(5) Fifth processing line installed, started operating late in August  
(6) Recession begins to affect construction industry  
(7) Average depreciation rate reduced from 22 to 18 years
### Table 10: 1400 STPD Refuse Power Plant (1): Specific Revenues

<table>
<thead>
<tr>
<th>Source</th>
<th>Revenues During Operating Year in US $/ST (2)</th>
<th>11-Year Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>66</td>
<td>67</td>
</tr>
<tr>
<td>1. Steam</td>
<td>4.19</td>
<td>4.35</td>
</tr>
<tr>
<td>2. Scrap Iron</td>
<td>0.56</td>
<td>0.68</td>
</tr>
<tr>
<td>3. Processed Ash</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>4. Resource Recovery</td>
<td>4.80</td>
<td>5.08</td>
</tr>
<tr>
<td>Σ 1, 2, 3</td>
<td>5.41</td>
<td>4.55</td>
</tr>
<tr>
<td>5. Tipping Fees (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ 4, 5</td>
<td>10.22</td>
<td>9.63</td>
</tr>
</tbody>
</table>

**Notes:**

1. Installed processing capacity in short tons of mixed municipal refuse per day when operating continuously.
   Municipal refuse is combusted in the "as-received condition" except bulky wastes which are sheared or shredded.
   Energy is recovered in form of superheated steam which is sold to a conventional power plant for the generation of electricity and supplying a district heating network.
   Coal is used as the basis for determining the price for the steam.
   Scrap iron, after separation from the ash, is compacted and baled for sale to steel makers.
   Processed ash is sold by a private contractor to construction projects.

2. Specific revenues expressed in US Dollars per short ton of refuse processed. 1 DM = .395 US $ and 1.0 MT = 1.1 ST were used for conversion.

3. This source represents an average which is composed of tipping fees actually charged to industrial and commercial users as well as neighboring municipalities. Also included in this average is a subsidy provided by the city government which covers the difference between expenses and receipts. The city charges its residents a container rental fee which covers the total cost of refuse collection and disposal. The disposal portion of this fee essentially makes up the subsidy.

4. This disproportionate increase is mainly due to the installation and startup of a fifth processing line.
unit \((2.00 \times 10^6 \text{ kg/h})\) for the Stuttgart project.

While income from resource recovery showed an overall increase together with the aforementioned increase in total income, it is interesting to note that the ratio of income from resource recovery to total income remained nearly constant at 0.52.

In order to eliminate the effects of plant modifications and waste collection charges, income in all four major categories was divided by the actual tonnage of refuse input processed. The resulting specific revenues are tabulated in Table 10, and may be helpful in comparing the Flingern RPP with other plant designs.

**ANNUAL EXPENSES**

As previously stated, the Flingern RPP is owned by the Duesseldorf Department of Sanitation, which in turn has contracted with Stadtwerke A.G. for engineering, construction and operating services.

Table 11 displays the expenses incurred by both the Stadtwerke and the Department of Sanitation. Stadtwerke expenses are given in five major categories: direct expenses for operations and maintenance (O & M), wage burden, materials burden, general and administrative (G & A), and finally, overhead. Of these five, materials burden, with \(\pm 1336\) percent, showed the highest gain, and G & A, with \(+202\) percent, the lowest gain for the 11-year period under study. O & M showed a small but steady increase until 1972, when the newly installed fifth processing line made itself felt, causing a significant escalation in O & M expenses.

Wage burdens approximately doubled during the first six years of plant operation and then, after 1972, practically tripled within five years. One of the reasons for this steep incline is the extraordinary wage and benefit package secured by labor in the second period. Startup of the fifth line, with its additional personnel requirements, was an additional reason.

G & A showed a steady and almost uniform gain, which is nearly comparable to that of O & M. Overhead behavior is comparable to that in the wage burden category, in that nearly uniform annual increments before 1972 were replaced by progressively larger increments leading to a 544 percent total increase of Stadtwerke expenses for the 11-year period.

All expenses lumped together accounted for, with the exception of 1975, a steadily increasing value of the annual operating contract between the two entities involved. Expenses on behalf of the Department of Sanitation fall into two categories: special expenses and capital service.

Special expenses are incurred by the Department of Sanitation in the administration and supervision of the whole RPP operation. This item may also include a modest reserve fund which is used to even annual budget deficits or surpluses, plus paying for the removal of ash processed but not sold. In the case of private ownership, this category would also contain a profit margin.

Capital service remained nearly constant — as one would expect — until 1973, when addition of the fifth line took effect. The year 1975 saw another significant increase due to the accelerated depreciation which started at that point. Still, with a gain of only 140 percent in eleven years, capital service showed the smallest gain of any category.

The ratio of capital expense to total expenses showed a nearly steady decline from 0.48 in 1966 to 0.30 in 1974, until the aforementioned change in depreciation interfered. Still, this ratio showed an overall decline of 24 percent during the observation period, reinforcing the view that the initial decision in favor of resource recovery was a prudent one.

By dividing annual expenses by the annual tonnages of refuse actually processed, specific expenses are generated which are contained in Table 12. This table contains no spectacular surprises, but it shows more clearly the extraordinary rise in specific overhead (up 406 percent*) and, by comparison, the rather modest increase in specific capital cost (up 71 percent). The latter would have been even less, possibly under 10 percent, if it had not been for the change in depreciation schedules.

**OPERATING ECONOMICS**

A summary of the Flingern RPP operating economics is displayed by Fig. 4. It is a requirement of municipal law that the annual budget be balanced. Any deficits or surpluses must be adjusted during the following year, mainly by projecting a larger or smaller tipping fee.

In this context, it should be realized that waste processing and disposal by a RPP represents only a

---

*This figure is lower than the 544 percent given in Table 11 because the specific expenses presented in Table 12 benefit from the increases in the annual tonnages of wastes processed.
### TABLE 11 1400 STPD REFUSE POWER PLANT(1): ANNUAL EXPENSES(2) (IN $ X 1000)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>949.</td>
<td>102.</td>
<td>11.</td>
<td>41.</td>
<td>154.</td>
<td>1,104.</td>
<td>78.</td>
<td>1,106.</td>
<td>2,288.</td>
<td>0.483</td>
</tr>
<tr>
<td>67</td>
<td>1,102.</td>
<td>120.</td>
<td>12.</td>
<td>51.</td>
<td>183.</td>
<td>1,285.</td>
<td>108.</td>
<td>1,106.</td>
<td>2,499.</td>
<td>0.443</td>
</tr>
<tr>
<td>68</td>
<td>1,200.</td>
<td>146.</td>
<td>14.</td>
<td>57.</td>
<td>217.</td>
<td>1,416.</td>
<td>131.</td>
<td>1,297.</td>
<td>2,844.</td>
<td>0.456</td>
</tr>
<tr>
<td>69</td>
<td>1,341.</td>
<td>152.</td>
<td>20.</td>
<td>65.</td>
<td>237.</td>
<td>1,579.</td>
<td>140.</td>
<td>1,266.</td>
<td>2,984.</td>
<td>0.424</td>
</tr>
<tr>
<td>70</td>
<td>1,474.</td>
<td>164.</td>
<td>23.</td>
<td>72.</td>
<td>259.</td>
<td>1,732.</td>
<td>99.</td>
<td>1,228.</td>
<td>3,059.</td>
<td>0.401</td>
</tr>
<tr>
<td>71</td>
<td>1,710.</td>
<td>196.</td>
<td>21.</td>
<td>85.</td>
<td>302.</td>
<td>2,012.</td>
<td>95.</td>
<td>1,231.</td>
<td>3,338.</td>
<td>0.369</td>
</tr>
<tr>
<td>72 (5)</td>
<td>1,937.</td>
<td>239.</td>
<td>23.</td>
<td>95.</td>
<td>357.</td>
<td>2,294.</td>
<td>193.</td>
<td>1,270.</td>
<td>3,757.</td>
<td>0.338</td>
</tr>
<tr>
<td>73</td>
<td>2,345.</td>
<td>511.</td>
<td>113.</td>
<td>88.</td>
<td>712.</td>
<td>3,058.</td>
<td>212.</td>
<td>1,527.</td>
<td>4,796.</td>
<td>0.318</td>
</tr>
<tr>
<td>74 (6)</td>
<td>2,841.</td>
<td>552.</td>
<td>150.</td>
<td>109.</td>
<td>811.</td>
<td>3,652.</td>
<td>277.</td>
<td>1,692.</td>
<td>5,621.</td>
<td>0.301</td>
</tr>
<tr>
<td>75 (7)</td>
<td>2,788.</td>
<td>626.</td>
<td>124.</td>
<td>101.</td>
<td>851.</td>
<td>3,639.</td>
<td>229.</td>
<td>2,743.</td>
<td>6,611.</td>
<td>0.415</td>
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<tr>
<td>76</td>
<td>3,287.</td>
<td>709.</td>
<td>158.</td>
<td>124.</td>
<td>991.</td>
<td>4,279.</td>
<td>282.</td>
<td>2,659.</td>
<td>7,219.</td>
<td>0.368</td>
</tr>
<tr>
<td>Totals</td>
<td>20,974</td>
<td>3,517</td>
<td>669.</td>
<td>888.</td>
<td>5,074.</td>
<td>26,050</td>
<td>1,844</td>
<td>17,125.</td>
<td>45,016.</td>
<td>-</td>
</tr>
<tr>
<td>Averages</td>
<td>1,907.</td>
<td>318.</td>
<td>61.</td>
<td>81.</td>
<td>461.</td>
<td>2,368.</td>
<td>168.</td>
<td>1,557.</td>
<td>4,092.</td>
<td>0.392</td>
</tr>
<tr>
<td>11-Year Changes</td>
<td>+246%</td>
<td>+595%</td>
<td>+1,336%</td>
<td>+202%</td>
<td>+544%</td>
<td>+288%</td>
<td>+262%</td>
<td>+140%</td>
<td>+216%</td>
<td>-24%</td>
</tr>
</tbody>
</table>

Notes:  
1. Installed processing capacity in short tons of mixed municipal refuse operating continuously  
2. 1 DM = 0.395 US $ was used for conversion; no attempt was made to allow for inflation and/or fluctuations in the currency exchange rate  
3. Includes salaries, wages, materials, subcontracts, utilities, etc.  
4. Includes insurance for equipment damage and service interruption, administrative expenses such as EDP, yard attendance such as scale operation and special handling of certain wastes, landfiling of ash not sold, etc.  
5. Fifth processing line installed, started operating late in August  
6. Recession begins to affect construction industry  
7. Average depreciation rate reduced from 22 to 18 years
<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>EXPENSES DURING OPERATING YEAR IN $/ST (1)</th>
<th>11-YEAR CHANGES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>66</td>
<td>67</td>
</tr>
<tr>
<td>1. Direct Expenses (2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;O&amp;M&quot;</td>
<td>4.23</td>
<td>4.25</td>
</tr>
<tr>
<td>2. Wage Burden (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.46</td>
<td>0.46</td>
</tr>
<tr>
<td>3. Materials Burden (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>4. General &amp; Administrative (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;G&amp;A&quot;</td>
<td>0.18</td>
<td>0.20</td>
</tr>
<tr>
<td>5. Overhead</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I 2, 3, 4</td>
<td>0.69</td>
<td>0.70</td>
</tr>
<tr>
<td>6. Total-Municipal Works (3)(4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I 1, 5</td>
<td>4.93</td>
<td>4.96</td>
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<tr>
<td>7. Special Expenses - Dept. of Sanitation (3)(5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I 6, 7</td>
<td>0.35</td>
<td>0.42</td>
</tr>
<tr>
<td>8. Total Project Expenses Dept. of Sanitation I 8, 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I 6, 7</td>
<td>5.28</td>
<td>5.37</td>
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<tr>
<td>9. Capital Service (3)(6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;A&amp;I&quot;</td>
<td>4.93</td>
<td>4.26</td>
</tr>
<tr>
<td>10. Total Expenses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I 8, 9</td>
<td>10.22</td>
<td>9.63</td>
</tr>
</tbody>
</table>

NOTES: (1) Specific expenses expressed in U. S. Dollars per short ton of refuse processed.
For conversion use 1 DM = $0.395 US$ and 1.0 MT = 1.1 ST
(2) This category includes salaries, wages, materials, subcontracts, utilities, etc.
(3) Excerpts taken from the plant operator's annual reports.
(4) The Municipal Works Department is under contract to the Department of Sanitation to "engineer, construct and operate the Refuse Power Plant".
(5) The Department of Sanitation of the host city is the owner of the Refuse Power Plant who provides supervision, does the accounting, pays insurance, etc.
(6) "A&I" stands for amortization and interest
(7) This disproportionate increase is due to a change in depreciation rates which was made in order to bring this plant in line with the general practices agreed upon by the "National Association of District Heating Plant Operators - Refuse Power Plant Section." The average depreciation rate of 22 years previously used was shortened to approximately 18 years.
small portion of the complete waste management requirements of a city like Duesseldorf. In a typical year, such as 1975, the cost to the Department of Sanitation for the disposal of refuse discarded by the Duesseldorf citizenry averaged $52.52/ton (58 mills/kg). Of this total, $43.37 (48 mills) was required to cover collection and transportation of the refuse, whereas only $9.15 (10 mills) was charged by the RPP for actual disposal [9, 10]. In other words, 82.6 percent of the city’s solid waste management expenditures was retained by the Department of Sanitation, compared to 17.4 percent passed on to Stadtwerke A.G. for RPP refuse disposal.

From Fig. 4 it is apparent that most of the plant revenues come from resource recovery with the remainder from tipping fees; that is, 51.8 percent and 48.2 percent respectively, a relationship which has remained fairly constant over the years.

It would be interesting to gauge the impact which the elimination of back-end materials recovery would have. Since that end of the plant is operated by a relatively small crew and requires only negligible energy, the result would be an average loss of 5 percent to 6 percent in revenues, a loss which would have to be offset by a corresponding increase in tipping fees. For example, even in 1976 which was a below-average year for materials recovery, $281,700 was realized from the sale of recovered materials, while only $4200 was expended for the electricity required to operate the materials recovery system. Other expenses, such as labor and equipment, would not be substantially affected if materials recovery was eliminated, because the residues resulting from combustion would need to be collected and removed in either case. Any savings would be absorbed by added spending for transportation and landfiling. Therefore, a hike in tipping fees would be the direct consequence of the elimination of materials recovery. These considerations suggest that the addition of materials recovery to energy recovery was another wise decision, even allowing for tolerable fluctuations in the value of the scrap iron produced.

In the expense category, the majority of 57.9 percent goes to the Stadtwerke A.G. for plant operations. The remainder of 42.1 percent is associated with ownership by the Department of Sanitation. It would be interesting to estimate the effect which a different project structure would produce, at, for example, Essen-Karnap, FRG, or Hempstead, USA, where ownership and operations are the responsibility of a single corporation.

**THERMAL PERFORMANCE**

When comparing refuse-fired boilers with fossil fuel-fired boilers, such as a pulverized coal-fired boiler, one must remember that, due to the higher moisture content of refuse, volumetric flow rates in refuse-fired boilers are always bound to be significantly higher. Furthermore, depending on the shape and type of the refuse fired, grate configuration, excess air ratio, and boiler aerodynamics, refuse firing tends to lead to increased particulate loadings and subsequently to more frequent fouling and/or erosion of boiler tubes. This in turn leads to a degradation in thermal performance and increased down-times.

Refuse derived flue gases can also carry gaseous trace contaminants such as CO, HCl, or HF which either individually or in combination with each other can cause boiler tube corrosion, a fact which is aggravated in the Flingern RPP by high operating conditions in terms of pressure and temperature. The corrosive effects of the flue gases are also detrimental to the performance of the gas cleaning system which follows the boiler. This is mainly due to increased flue gas dew point temperatures, and, in order to avoid condensation in this part of the system, boiler outlet temperatures must be kept higher than with comparable fossil fuels.

While excess air may be beneficial to improved combustion and help to reduce corrosion in the lower furnace water-walls, it does not improve thermal performance. The inert fraction of volumetric flow increases, leading to additional losses.

While many plants are designed for and operated at air excess ratios of close to 100 percent, the Flingern plant generally operates at 73 percent with no apparent detrimental effects.

All of the conditions outlined above have been encountered at one point or another at the Flingern RPP. While they have not seriously interfered with the successful operation of this plant, they have nevertheless reduced thermal performance to a less than ideal level.

As previously indicated, a steady rise in the heating value of refuse has also led to a commensurate rise in specific steaming rates, up from 1.59 in 1966 to 2.07 in 1976, with the average at 1.81 lb steam per lb waste. By comparison, newer plants in Europe and the United States are now being designed for steaming rates at about 3.00 lb/lb to allow for the processing of high Btu wastes.

In addition to the aforementioned considerations, there are seasonal fluctuations in the quantity and
Note: Analysis based on a summation of annual totals

FIG. 4 1400 STPD REFUSE POWER PLANT: REVENUES VS. EXPENSES – 11 YEAR AVERAGES
### TABLE 13: 1400 STPD REFUSE POWER PLANT: SEASONAL VARIATIONS IN 1976 THERMAL PERFORMANCE (1)

<table>
<thead>
<tr>
<th>Plant Operating Month</th>
<th>Refuse Combustion &amp; Heat Release</th>
<th>Steam Generation</th>
<th>Heat Losses &amp; Thermal Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Refuse (2) Processed (3) ST</td>
<td>Refuse Heat Content (LHV) Btu/Lb</td>
<td>Oxygen (4) &amp; Excess (4) Flue Gas (4) Exit Temp. °F</td>
</tr>
<tr>
<td>January</td>
<td>29,45C</td>
<td>3,155</td>
<td>8.83</td>
</tr>
<tr>
<td>February</td>
<td>28,680</td>
<td>3,226</td>
<td>9.18</td>
</tr>
<tr>
<td>March</td>
<td>27,790</td>
<td>3,308</td>
<td>9.29</td>
</tr>
<tr>
<td>April</td>
<td>26,200</td>
<td>3,400</td>
<td>9.05</td>
</tr>
<tr>
<td>May</td>
<td>27,82C</td>
<td>3,231</td>
<td>9.02</td>
</tr>
<tr>
<td>June</td>
<td>22,810</td>
<td>3,143</td>
<td>8.58</td>
</tr>
<tr>
<td>July</td>
<td>25,690</td>
<td>3,485</td>
<td>8.50</td>
</tr>
<tr>
<td>August</td>
<td>21,354</td>
<td>3,510</td>
<td>8.55</td>
</tr>
<tr>
<td>September</td>
<td>22,290</td>
<td>2,936</td>
<td>8.64</td>
</tr>
<tr>
<td>October</td>
<td>26,100</td>
<td>3,238</td>
<td>9.02</td>
</tr>
<tr>
<td>November</td>
<td>31,160</td>
<td>3,013</td>
<td>8.99</td>
</tr>
<tr>
<td>December</td>
<td>27,790</td>
<td>3,320</td>
<td>8.73</td>
</tr>
<tr>
<td>Totals</td>
<td>317,044</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Averages</td>
<td>26,420</td>
<td>3,247(9)</td>
<td>8.87(10)</td>
</tr>
<tr>
<td>CV</td>
<td>37.1%</td>
<td>17.7%</td>
<td>8.9%</td>
</tr>
</tbody>
</table>

Notes:
1. Readouts from EDP system of plant operator
2. Weighted and recorded
3. Lower Heating Value (LHV) calculated by the indirect method (boiler heat balance).
4. Measured, but flue gas volume is estimated by using standard value of 5 m³/ton of refuse
5. Flowrate measured together with pressure and temperature at supply conditions
6. Depends to a large extent on the cleanliness of the boiler tubes
7. Estimated by using the end of the grate system and 750°F as temperature as the reference conditions
8. Estimated for this type and size boiler by using experience values
9. Final figures contained in the annual report submitted by the operator to the owner may vary slightly due to final adjustments
10. In order to obtain % excess air, use the formula: \[ \frac{21}{21 - 0.2} - 1 \] X 100%

For example, average % excess air can be calculated: \[ \frac{21}{21 - 8.87} - 1 \] X 100% = 73% (assuming complete combustion)
quality of wastes being fired, with variations in moisture content being the least desirable. Table 13 is typical for the seasonal fluctuations encountered during recent operating years.

The coefficients of variability (CV) for refuse processed and steam generated, with 37.1 percent and 32.4 percent respectively, are of the same magnitude and are largely independent of operator control. The same holds true for the heat content at 17.7 percent. By contrast, excess oxygen at 8.9 percent and flue gas exit temperature at 7.4 percent are clearly within the domain of the operator. The CV of 0.9 percent for the heat content of steam supplied on an average monthly basis must be considered as impressive.

The net boiler efficiency averaging 73.4 percent with a CV of 5.3 percent must be considered equally well controlled, taking into consideration the age and layout of the plant, as well as the foregoing discussion. While better performance could be attained with a pure fossil fuel-fired boiler system, this is not necessary, because of the coupling between the RPP and the EPS, whereby the RPP supplies only one-third of the annual steam consumption by the turbines and the district heating network. The other two-thirds are supplied by the conventional power boilers, firing bituminous and lignite coals, at the EPS.

A more graphic presentation is given by the sector diagram in Fig. 5.

ENERGY CONVERSION AND UTILIZATION

The RPP is linked with the EPS through an overground piping network, which is approximately 2300 ft in length (7.01 x 10^2 m). This network consists of one high pressure line to deliver an annual baseload of 150,000 lb/hr (6.80 x 10^4 kg/h) at 1179 psig (8.13 x 10^6 Pa) and 881 F (472 C) average conditions. Since this delivery is somewhat below the 1209 psig (8.34 x 10^6 Pa) and 923 F (495 C) reference conditions, a penalty clause is usually in effect which slightly diminishes potential earnings on steam sales by adjusting “supply tons” to “accounting tons.” In 1976, for example, 652,000 tons (5.91 x 10^8 kg) of steam were supplied by the RPP to the EPS, but only 621,000 tons (5.63 x 10^8 kg) were accounted for (see Table 5). A second high pressure line is planned for a later date to coincide with the installation of the sixth processing line.

A single medium pressure line serves as a two-way flow passage between the RPP and EPS. It can be used either to supply steam for boiler startup and intermittent sootblowing, or to receive steam during boiler shutdown and depressurization of high pressure parts. Generally, the flow balance is positive, with a modest surplus going to the EPS. This surplus is then corrected to high pressure conditions and added to the high pressure steam sold for accounting purposes. Conversely, in case of a deficit in the medium pressure system, necessary subtractions are made.

Finally, a third line serves as a 100 percent condensate return, so that feedwater treatment is not needed in the RPP. For convenience purposes, this feedwater is first used in the RPP for air preheating and space heating before entering the boiler system, a fact which further complicates thermal analysis.

Table 14 contains additional descriptive details.

The Flingern EPS #1 is equipped with four boilers which fire combinations of bituminous and lignite coals and have a combined steaming capacity of 990,000 lb/hr (4.49 x 10^5 kg/h) of superheated steam. Under normal conditions, the Flingern EPS #1 operates as a true congeneration plant, selling electricity, steam, and hot water to a variety of residential, commercial, and industrial customers. The particular mix of boilers in use at any given time depends primarily on load conditions in the Duesseldorf energy market.

Table 15 presents the 1976 annual energy budget for the Flingern EPS #1, which can be considered as fairly typical for recent years. Utilizing a mix of high pressure and intermediate pressure extraction turbines, only 58 percent of the saleable output is electrical, whereas 42 percent is thermal; that is, the main purpose of this plant is to supply the growing needs of Duesseldorf’s large district heating network, rather than to be the major supplier of electricity.

Due to the local climate, little if any air conditioning is required during the summer, so that thermal loads undergo seasonal fluctuations. As a result, the average, annual, and net energy utilization efficiency of about 42.7 percent is respectable when compared to electrical power generation only; but it is far from the optimum which could be achieved by year-round balancing of thermal loads. Such load balancing is a real possibility in the hot and humid climates of southern Europe and particularly in the United States where steam can be supplied to absorption refrigeration systems to provide air conditioning for large commercial and institutional buildings. The alternative would be to couple the RPP with the cogeneration facility.
8.87% avg. Excess $O_2$
3,240 Btu/lb avg. LHV
517° F avg. Flue Gas Temperature at Boiler Exit
26,420 ST/Month avg. Refuse Throughput
1,430 Btu/lb avg. Heat Content of Exported Steam
54,290 ST/Month avg. Steam Export
2.07 ST Steam/ST Refuse avg. Specific Steaming Rate

FIG. 5 1400 STPD REFUSE POWER PLANT: THERMAL PERFORMANCE 1976
TABLE 14 1400 STPD REFUSE POWER PLANT: ENERGY CONVERSION AND UTILIZATION

Energy Output from Flingern RPP: Baseload of 150,000 lb/hr Superheated Steam Delivered at an Average of 1,179 psig and 881°F. Cost and Quality of Coal Derived Steam Used to Determine Price of Steam with 1,209 psia and 923°F as the Reference Conditions.

Connection between Flingern RPP and EPS #1: 2,300 ft Overground Pipeline for HP- and LP-Steamp Delivery to Flingern EPS with 303°F Condensate Return.

Steam Power Generation in Flingern EPS #1: Two Boilers with Travelling Grates for Bituminous Coal and Suspension Burners for Lignite Powder Coal, Each Generating 187,000 lb/hr at 1,195 psig and 959°F. Two Boilers with Cyclone Burners for Both Bituminous and Lignite Powder Coal, Each Generating 308,000 lb/hr at 1,280 psig and 977°F. Combined Installed Capacity of 990,000 lb/hr.

Electrical Power Generation in Flingern EPS #1: HP-Steamp Received into Common Header to Drive 2 HP-Turbines (28 MW and 13.5 MW) Which Feed 2 MP-Condensing Turbines (50 MW and 32 MW) With a Combined Installed Capacity of 128.5 MW.

Connection between Flingern ESP #1 and DHN: Condensing-Type Heat Exchangers Supplied from Steam Connection Between First Stage and LP-Stages of the 50 MW Turbine Transfer Heat to DHN Which Uses Pressurized Hot Water as Working Fluid.

Description of Inner City DHN: Ten-Mile Long Piping Network Connects 133 Metered Customers (Including Kennedy Dam with Hilton and Intercontinental), Total Demand 400 Million Btu/hr (65 to 240 Million Btu/hr Supplied by RPP). Flow Rate 210,000 to 370,000 gph Depending on Season, Supply 176°F to 266°F, Return 149°F to 158°F, ∆T from 27°F to 108°F. Customers Sign 5- to 20-Year Energy Supply Contracts Which Include Demand and Use Charges.
### TABLE 15 ENERGY BUDGET - FLINGERN EPS #1(1)(2): ANNUAL TOTALS FOR 1976

<table>
<thead>
<tr>
<th>ENERGY BUDGET CATEGORY</th>
<th>ANNUAL TOTAL</th>
<th>PERCENTAGE OF SUBTOTAL</th>
<th>PERCENTAGE OF TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Billion Btu(3)</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>I. Heat Inputs (From Combustion)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) EPS (From Coal)</td>
<td>3,596</td>
<td>71.0</td>
<td>71.0</td>
</tr>
<tr>
<td>(2) RPP (From Refuse)(4)</td>
<td>1,468</td>
<td>29.0</td>
<td>29.0</td>
</tr>
<tr>
<td>Σ Inputs(5)</td>
<td>5,064</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>II. Energy Losses (Conversion and Distribution)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) EPS (Condenser)</td>
<td>2,413</td>
<td>83.1</td>
<td>47.7</td>
</tr>
<tr>
<td>(2) EPS (Boiler)</td>
<td>396</td>
<td>13.6</td>
<td>7.8</td>
</tr>
<tr>
<td>(3) EPS (Internal Consumption, Electric)</td>
<td>52</td>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>(4) EPS (Internal Consumption, Steam)</td>
<td>27</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>(5) DH(6) (Pumping)</td>
<td>15</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Σ Losses(5)</td>
<td>2,903</td>
<td>100.1</td>
<td>57.3</td>
</tr>
<tr>
<td>III. Saleable Outputs (Residential, Commercial, and Industrial Customers)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Electricity</td>
<td>1,262</td>
<td>58.4</td>
<td>24.9</td>
</tr>
<tr>
<td>(2) DH (Water)</td>
<td>799</td>
<td>37.0</td>
<td>15.8</td>
</tr>
<tr>
<td>(3) DH (Steam)</td>
<td>100</td>
<td>4.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Σ Outputs(5)</td>
<td>2,161</td>
<td>100.0</td>
<td>42.7</td>
</tr>
</tbody>
</table>

NOTES:  
(1) Flingern Electrical Power Station #1, which has a steaming capacity of 990,000 lb/hr and a generating capacity of 123.5 MW.  
(2) Source: Engineering Department of Stadtwerke A.G., Duesseldorf, FRG  
(3) To convert to Gcal, multiply by $\frac{1}{3.968 \times 10^3}$; to convert to Gwh, multiply by $\frac{1}{3.413}$  
(4) Refuse power plant with a steaming capacity of 242,000 lb/hr  
(5) Annual Energy Budget: $\Sigma$ Inputs = $\Sigma$ Losses + $\Sigma$ Outputs = 5,064 trillion Btu  
(6) District Heating Network
TABLE 16  1400 STPD REFUSE POWER PLANT: BREAKDOWN OF INTERNAL ELECTRICAL POWER CONSUMPTION

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Components</th>
<th>Power Consumption$^{(1)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>KWH/ST$^{(2)}$</td>
</tr>
<tr>
<td>1. Steam Generation</td>
<td>Grates, Drives, Boiler, FD &amp; ID Fans, Feed Pumps, Ash Extractors, Controls, Etc.</td>
<td>32.7</td>
</tr>
<tr>
<td>2. Flue Gas Purification</td>
<td>E-Filter</td>
<td>3.6</td>
</tr>
<tr>
<td>3. Refuse Reception</td>
<td>Scales, Shears, Cranes, Feeders, etc.</td>
<td>1.8</td>
</tr>
<tr>
<td>4. Materials Processing</td>
<td>Conveyors, Screens, Mag-Separators, Baling Presses</td>
<td>0.5</td>
</tr>
<tr>
<td>5. Lighting</td>
<td>Internal (Lighting of Buildings)</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>External (Lighting of Site)</td>
<td></td>
</tr>
<tr>
<td>6. Miscellaneous</td>
<td>Pumps for Condensate &amp; Cooling Water, Drain Wells, Sewers, Elevators, Ventilators, etc.</td>
<td>1.1</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>43.6</td>
</tr>
</tbody>
</table>

Notes: (1) Estimates based on plant operating manual, motor lists for various subsystems and plant operator's observations
(2) Specific electrical power consumption in KWH per ST of refuse processed using the 1972 to 1976 average of 43.6 KWH/ST as the basis
(3) Expressed in percent of the total for specific electrical power consumption

of a large industrial complex with nearly constant production schedules, such as a paper mill or chemical plant. In this case, most of the extraction steam would be used for process purposes, rather than for space heating and/or hot water production.

In the case of Duesseldorf, the RPP serves primarily as a base load supplier to the EPS. Referring again to Table 13, it can be seen that, in 1976, monthly deliveries averaged 54,000 tons (4.90 x 10$^7$ kg) of superheated steam with the minimum at 40,000 tons (3.03 x 10$^7$ kg) and the maximum at 60,000 tons (5.44 x 10$^7$ kg). Peak deliveries occurred during January, July, and November. It can be easily recognized that these peaks correspond to changes in refuse quantity and composition. For example, the January and December peaks coincided with peaks in the amount of refuse processed, whereas the July peak coincided with the peak in the heat content of the refuse.

In order to accomplish its twofold objective of waste disposal and steam generation, the RPP needs electricity, which is purchased from the EPS on an annual basis. In 1976, the EPS had a total saleable electrical output of 1262 billion Btu (1.33 x 10$^{15}$ J), or 369.9 GWh; of which 49.6 billion Btu (5.23 x 10$^{13}$ J), or 14.5 GWh, were sold back to the RPP for internal consumption. However, this amount represents only about 3.9 percent of EPS electrical net output and 2.3 percent of its combined electrical and thermal outputs.

Table 16 shows how this electrical energy was used in the RPP during the 1972-1976 period of time. Specific power consumption was established by dividing electricity purchased by the tonnage of refuse processed. Most of the resulting 43.6 kWh/ton (4.81 x 10$^{-2}$ kWh/kg), specifically 32.7 kWh/ton (3.60 x 10$^{-2}$ kWh/kg) or 74.9 percent, went into boiler operations, while only 0.5 kWh/ton (5.51 x 10$^{-4}$ kWh/kg) or 1.1 percent, was required for post-combustion material recovery.

Table 15 also shows the energy impact of coupling the RPP with the EPS. In 1976, the RPP supplied a net total of about 1500 billion Btu (1.58 x 10$^{15}$ J) to the EPS in the form of refuse derived steam. Thus, by providing 29 percent of the total annual energy budget at the Flingern EPS #1, refuse power made a major contribution towards energy conservation and the stretching of non-renewable fossil fuel supplies in the Duesseldorf area.
More specifically, during 1976, the RPP saved the EPS about 76,000 tons (6.89 x 10^7 kg) of standard coal*, or about 12.8 million gal (4.85 x 10^6 m^3) of medium sulfur fuel oil. In addition to these savings in primary energy from the direct use of refuse power, there are further savings from the post-combustion processing and recovery of materials. During 1976, the RPP recovered and sold 9400 tons (8.53 x 10^6 kg) of ferrous scrap for use in steel smelters. Utilizing the information previously developed in Appendix IV, additional savings in primary energy on the order of 10,000 tons (9.07 x 10^6 kg) of standard coal, or 1.95 million gal (7.38 x 10^3 m^3) of fuel oil were estimated. By selling ash to the construction industry, the mining and transportation of regular aggregates along the banks of the Rhine River south of Duesseldorf has been reduced; but the investigation of energy savings along these lines is incomplete and, therefore, no estimates are included here.

From the above, it becomes apparent that during 1976, operation of the Flingern RPP made possible total energy savings for the economy of the State of North Rhine Westphalia in the order of 77,000 tons (6.99 x 10^7 kg) of standard coal, or 14.8 million gal (5.60 x 10^6 m^3) of fuel oil.

A more in-depth study of the effects of refuse power on energy conservation and environmental protection in Duesseldorf is underway, and its results will become the subject of a subsequent paper.

**OPERATING RESULTS**

During the first six and a half years of RPP operations at Flingern, boiler tube corrosion was the major recurring problem [11]. Chemical reactions between the tube material, or the iron oxide protective scale, and hydrochloric acid were identified as the reason. Before taking corrective action, extensive tests were performed by removing tube samples for laboratory analysis, measuring O_2 concentrations at various points in the flue gas stream, and modeling flow conditions in water tanks. Subsequently, the furnace configuration was changed by constructing an arch-like wall of firebrick to prevent the direct flow of the gases along the roof of the furnace into the first boiler pass. Secondary air nozzles were provided directly in front of the wall to ensure a better vortical intermixture of air and gas. Also, bulky wastes were shredded and blended better with refuse of lower calorific value to avoid violent variations in combustion conditions. Finally, the refuse feeder was modified to provide a more uniform rate of feed.

Subsequent corrosion problems due to changes in refuse characteristics, especially due to increases in wrapping materials and wood, were alleviated by procuring a new tube material (high alloy austenitic steel). Also, a new combustion control system was installed to even out the combustion capacity [12].

When the fifth and larger processing line was installed in 1972, its furnace configuration was changed from counterflow to parallel flow, with the objectives of forcing more intensive and uniform combustion within the furnace chamber and allowing addition reaction time for burnout before reaching the heat transfer surfaces [13].

A shredder was installed in 1973 to increase the rate of bulky wastes reduction. Under normal conditions, the shredder experienced only modest wear and consistently demonstrated a high unit availability of 94 percent to 95 percent. Two specific incidents which caused an unavoidable temporary loss of availability were a fire in the plant and an explosion in the shredder itself [14].

The result of the learning experience and the many improvements made in the Flingern RPP can be best summarized by quoting from the operator's report:

"...in spite of corrosion problems, economical energy recovery in the form of high pressure, high temperature steam generation is possible by refuse incineration in practically normal water-wall units..." [11]

Table 17 discusses annual RPP performance characteristics, such as steaming rates, boiler efficiencies, and capacity factors. From this table, it is apparent that plant operations improved rather rapidly during the early years, but then levelled off during the later years, a fact which attests to the maturity of plant operations. It is of particular interest to note that the capacity factors of the grates and boilers have now reached the same level, indicating that a good match has been achieved between these two vital parts of the system.

In order to be in a better position to judge the accomplishments at the Flingern RPP, Table 18 was compiled, which compares the plant capacity factors for all large refuse power plants in the FRG. With an average plant capacity factor (PCF) of 57.5, the Duesseldorf Roller Grate System exceeds the national average of 51.8 percent. The Flingern RPP, with 65.2 percent, is way above the

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*Means bituminous coal with a lower heating value of 7000 kcal/kg (2.93 X 10^4 kJ/kg).

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TABLE 17 1400 STPD REFUSE POWER PLANT: MAJOR PERFORMANCE PARAMETERS(1)

<table>
<thead>
<tr>
<th>PLANT OPERATING YEAR</th>
<th>LOWER HEATING VALUE</th>
<th>BOILER THERMAL EFFICIENCY (2)</th>
<th>SPECIFIC (3) STEAMING RATE</th>
<th>STEAM CONFORMANCE FACTOR (4)</th>
<th>SPECIFIC ELECTRICAL POWER CONSUMPTION (5)</th>
<th>CAPACITY FACTOR (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8tu/lb</td>
<td>%</td>
<td>ST/ST</td>
<td>ST/ST</td>
<td>KWh/ST</td>
<td>%</td>
</tr>
<tr>
<td>1966</td>
<td>2,468</td>
<td>69.1</td>
<td>1.59</td>
<td>0.919</td>
<td>35.4</td>
<td>58.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46.2</td>
</tr>
<tr>
<td>1967</td>
<td>2,621</td>
<td>68.8</td>
<td>1.58</td>
<td>0.963</td>
<td>32.1</td>
<td>67.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>52.9</td>
</tr>
<tr>
<td>1968</td>
<td>2,792</td>
<td>68.6</td>
<td>1.67</td>
<td>0.926</td>
<td>31.0</td>
<td>73.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>61.0</td>
</tr>
<tr>
<td>1969</td>
<td>2,882</td>
<td>68.4</td>
<td>1.71</td>
<td>0.939</td>
<td>31.9</td>
<td>75.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>64.2</td>
</tr>
<tr>
<td>1970</td>
<td>2,948</td>
<td>68.6</td>
<td>1.82</td>
<td>0.920</td>
<td>33.6</td>
<td>73.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>66.4</td>
</tr>
<tr>
<td>1971 (7)</td>
<td>3,087</td>
<td>69.5</td>
<td>1.87</td>
<td>0.938</td>
<td>35.3</td>
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<td>69.9</td>
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<td>0.942</td>
<td>41.7</td>
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<td>1973</td>
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<td>1974 (9)</td>
<td>2,857</td>
<td>69.2</td>
<td>1.74</td>
<td>0.948</td>
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<td>1975</td>
<td>3,147</td>
<td>72.3</td>
<td>1.99</td>
<td>0.948</td>
<td>43.1</td>
<td>64.4</td>
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<td>61.3</td>
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<td>1976</td>
<td>3,247</td>
<td>73.4</td>
<td>2.07</td>
<td>0.952</td>
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<td>61.5</td>
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11-YEAR STATISTICS

<table>
<thead>
<tr>
<th>MIN.</th>
<th>2,468</th>
<th>68.4</th>
<th>1.58</th>
<th>0.919</th>
<th>31.0</th>
<th>58.1</th>
<th>46.2</th>
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<tr>
<td>AVG.</td>
<td>2,932</td>
<td>69.9</td>
<td>1.80</td>
<td>0.941</td>
<td>37.9</td>
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<tr>
<td>MAX.</td>
<td>3,247</td>
<td>73.4</td>
<td>2.07</td>
<td>0.952</td>
<td>46.2</td>
<td>75.2</td>
<td>65.4</td>
</tr>
<tr>
<td>Δ%</td>
<td>+31.6%</td>
<td>+6.2%</td>
<td>+30.2%</td>
<td>+3.6%</td>
<td>+30.5%</td>
<td>+6.4%</td>
<td>+33.1%</td>
</tr>
<tr>
<td>C.V.</td>
<td>+26.6%</td>
<td>+7.2%</td>
<td>+27.2%</td>
<td>+3.5%</td>
<td>+40.1%</td>
<td>+25.5%</td>
<td>+32.3%</td>
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</tbody>
</table>

NOTES: (1) Computations from Tables 1, 4, 5.
(2) Composite boiler thermal efficiency from EDP summaries for boilers 1 to 4 during 1966 to 1972 period, and for boilers 1 to 5 during 1972 to 1976 period.
(3) ST Steam/ST Refuse. The design value for boilers 1 to 4 is 2.00, compared to 2.36 for boiler 5. The design value for the mix of boilers 1 to 5 is 2.09.
(4) Accounting Tons/Supply Tons
(5) KWh/ST Refuse; breakdown more meaningful using 1966 to 1971 and 1972 to 1976 periods, because major equipment modifications in 1971 resulted in increased specific power consumption: 1966 to 1971 period average is 33.2 KWh/ST and 1972 to 1976 period average is 43.6 KWh/ST. The 1972 to 1976 average is adversely affected by the absence of the sixth processing line for which provisions in terms of fans, pumps, and filters have already been made.
(6) Up to 1976, grate capacity, equipment availability, and refuse logistics controlled overall plant capacity. Due to continued increases in the heating value of refuse, boiler capacity emerges now as the controlling factor.
(7) Major equipment modifications made.
(8) Fifth processing line started up.
(9) OPEC price cartel affects fossil fuel prices.
<table>
<thead>
<tr>
<th>PLANT NAME</th>
<th>ANNUAL DESIGN CAPACITY</th>
<th>NUMBER OF INSTALLED GRATE UNITS</th>
<th>ANNUAL THROUGHPUT</th>
<th>PLANT (3) CAPACITY FACTOR</th>
<th>TYPE OF GRATE USED (4)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>X 1,000 ST</td>
<td></td>
<td>X 1,000 ST</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Berlin</td>
<td>1,100</td>
<td>8</td>
<td>440</td>
<td>40.0</td>
<td>VKW-Roller Grate</td>
</tr>
<tr>
<td>Bremen</td>
<td>434</td>
<td>3</td>
<td>198</td>
<td>45.6</td>
<td>VKW-Roller Grate</td>
</tr>
<tr>
<td>Darmstadt</td>
<td>308</td>
<td>3</td>
<td>132</td>
<td>42.9</td>
<td>Von Roll-F. F. Reciprocating</td>
</tr>
<tr>
<td>Duesseldorf</td>
<td>506</td>
<td>5</td>
<td>330</td>
<td>65.2</td>
<td>VKW-Roller Grate</td>
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<tr>
<td>Essen-Karnap</td>
<td>964</td>
<td>5</td>
<td>391</td>
<td>40.6</td>
<td>VKW-Travelling Grate</td>
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<tr>
<td>Frankfurt/Main</td>
<td>578</td>
<td>4</td>
<td>340 (5)</td>
<td>58.8</td>
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<tr>
<td>Hagen</td>
<td>173</td>
<td>3</td>
<td>110</td>
<td>63.6</td>
<td>VKW-Roller Grate</td>
</tr>
<tr>
<td>Hamburg I</td>
<td>452</td>
<td>6</td>
<td>286</td>
<td>63.3</td>
<td>Von Roll/Martin</td>
</tr>
<tr>
<td>Hamburg II</td>
<td>376</td>
<td>2</td>
<td>286</td>
<td>76.1</td>
<td>Martin-R. F. Reciprocating</td>
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<tr>
<td>Iselhohn</td>
<td>308</td>
<td>3</td>
<td>114</td>
<td>37.0</td>
<td>VKW-Travelling Grate</td>
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<tr>
<td>Kassel</td>
<td>193</td>
<td>2</td>
<td>121</td>
<td>62.7</td>
<td>VKW-Roller Grate</td>
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<tr>
<td>Leverkusen</td>
<td>193</td>
<td>2</td>
<td>117</td>
<td>60.6</td>
<td>Von Roll-F. F. Reciprocating</td>
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<tr>
<td>Ludwigshafen</td>
<td>424</td>
<td>3</td>
<td>165</td>
<td>38.9</td>
<td>KSG-Travelling Grate</td>
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<tr>
<td>Mannheim</td>
<td>642 (6)</td>
<td>3</td>
<td>253</td>
<td>39.4</td>
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<tr>
<td>Muenchen-Nord</td>
<td>714 (6)</td>
<td>2</td>
<td>242</td>
<td>33.9</td>
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<td>Muenchen-Sued</td>
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<td>3</td>
<td>204</td>
<td>47.0</td>
<td>Von Roll-F. F. Reciprocating</td>
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<td>Nuernberg</td>
<td>636</td>
<td>3</td>
<td>385</td>
<td>60.5</td>
<td>VKW-Roller Grate</td>
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<tr>
<td>Oberhausen</td>
<td>289</td>
<td>3</td>
<td>187</td>
<td>64.7</td>
<td>VKW-Roller Grate</td>
</tr>
<tr>
<td>Offenbach</td>
<td>193</td>
<td>2</td>
<td>99</td>
<td>51.3</td>
<td>Von Roll-F. F. Reciprocating</td>
</tr>
<tr>
<td>Solingen</td>
<td>578</td>
<td>3</td>
<td>275</td>
<td>47.6</td>
<td>VKW/Martin</td>
</tr>
</tbody>
</table>

A. ANALYSIS FOR COMPLETE SAMPLE (N = 21)

| TOTAL         | 9,688                  | 70                              | 4,769             | 1,088.4                    |                      |
| MINIMUM       | 173                    | 2                               | 94                | 33.9                      |                      |
| AVERAGE       | 461                    | 3.33                            | 227               | 51.8                      |                      |
| MAXIMUM       | 1,100                  | 8                               | 440               | 76.1                      |                      |
| C.V.          | 201                    | 180                             | 152               | 81.5                      |                      |

B. ANALYSIS FOR PLANTS WITH VKW GRATES (N = 9)

| TOTAL         | 4,603                  | 35                              | 2,276             | 479.9                      |                      |
| MINIMUM       | 173                    | 2                               | 110               | 37.0                      |                      |
| AVERAGE       | 511                    | 3.89                            | 253               | 53.3                      |                      |
| MAXIMUM       | 1,100                  | 8                               | 440               | 65.2                      |                      |
| C.V.          | 181                    | 154                             | 191               | 58.5                      |                      |

C. ANALYSIS FOR PLANTS WITH VKW ROLLER GRATES (N = 7)

| TOTAL         | 3,332                  | 27                              | 1,771             | 402.3                      |                      |
| MINIMUM       | 173                    | 2                               | 110               | 40.0                      |                      |
| AVERAGE       | 476                    | 3.86                            | 253               | 57.5                      |                      |
| MAXIMUM       | 1,100                  | 8                               | 440               | 65.2                      |                      |
| C.V.          | 195                    | 155                             | 130               | 43.8                      |                      |

NOTES: (1) Main Source: "Muellverbrennungsanlagen in der Bundesrepublik Deutschland," L. Barniske, Umweltbundesamt, Berlin, 1975 (Based on a study accomplished in 1974).
(2) Refuse power plants must meet the following criteria for inclusion in this analysis:
- Continuous Operation; that is, 8,760 h/y
- Unit Grate Capacities of ≥ 5 st/h
- Plant Capacities of ≥ 500 STPD
(3) Plant Capacity Factor = PCF = Annual Throughput ST / Design Capacity ST x 100%
(5) Discrepancy with information from main source; entry changed based on data received from plant operator.
(6) Approximation, because not all grate units installed were intended for continuous operation.
(7) Not included in analyses B and C because more than one type of grate was installed.
national average, and it is also the leader in its own class, followed closely by the Offenbach RPP with 64.7 percent.

When pondering the significance of the PCF, one must realize that this is the final expression for the success of any given project. PCF is an all-encompassing term which includes the conceptual approach to refuse flow control and plant layout in a particular community, as well as process design, equipment selection and operating methodology for a particular plant. For example, the unavailability of sufficient amounts of refuse cannot be totally compensated for by even the best in operational strategies, since the plant will simply remain overdesigned and underutilized.

With a PCF of 33.9 percent, Muenchen-Sued scores the lowest mark of any plant in the tabulation, mainly because of three reasons. First, two grate systems of huge dimensions (44 ton/hr capacity each) (3.99 x 10^4 kg/h) show less operational flexibility than would four units of smaller capacity (22 ton/hr, for instance) (2.00 x 10^4 kg/h), since any outage immediately reduces plant processing capacity by 50 percent (as opposed to 25 percent if smaller units had been used). Second, attempts to couple RPP operations with the peculiar electrical load profiles in the City of Muenchen were not overly successful, primarily because of the heterogeneous nature of refuse. Third, an institutional constraint is also imposed by the fact that the City Power Works cannot sell to the surrounding Bavarian State Power Works when it has excess electrical capacity [15].

In addition to the above considerations, the PCF also reflects on the reliability and availability of all installed equipment. This particular aspect is under intensive study at the present by the authors, and will be the subject of another subsequent paper.

Since RPPs are now being considered in the United States for supplementing existing fossil fuel supplies, utility companies are showing a renewed interest in refuse power. In this connection, it is logical to ask how well RPP's perform when compared to EPS's.

In Table 19, such a comparison is attempted by comparing coal-fired, nuclear fueled, and refuse-fired plants. It shows that RPP's equipped with the Duesseldorf System have a PCF of 57.5 percent, which compares favorably with that of the United States nuclear plants at 59.3 percent. The Flingern RPP, with a PCF of 65.2 percent, even comes close to the average United States coal-fired plants at 66.9 percent. This accomplishment is largely attributable to the high standards of its operating staff, drawn mainly from the city's utility operator, Stadtwerke A.G., rather than from its Department of Sanitation. From this comparison, it follows that well designed and well operated RPP's should meet the expectations of the United States utility industry.

Looking back over the first eleven years of operations at the Flingern RPP, several major operating results can be delineated, as shown in Table 20. About 3.2 million tons (2.90 x 10^9 kg) of refuse were processed with an average volume reduction efficiency of between 95 percent and 98 percent. The higher efficiency refers to the years in which more than half of the ash was sold for construction purposes. This high volumetric reduction drastically reduced landfill requirements in the Duesseldorf area by an estimated 600 million ft^3 (1.70 x 10^7 m^3). Additional savings were accomplished by the sharply reduced demand for daily cover material.

During the 11-year review period, the Flingern RPP processed a total of 3.2 million tons (2.90 x 10^9 kg) of refuse in 96,400 hr of continuous operations, a truly exemplary record, considering the difficulties associated with refuse as a fuel and the design constraints encountered during inception of the project. Considerable experience has been developed during these operations; perhaps one way to express the aggregate of this experience is to multiply tonnages processed by hours operated. The result is 308 billion ton-hr (2.79 x 10^{14} kg-hr) of operating experience, a comprehensive term which, in the opinion of the authors, is appropriately descriptive of the scale and duration of the operations performed at the Flingern RPP.

In terms of a financial summary, it can be reported that for the disposal of 3.2 million tons (2.40 x 10^9 kg) of refuse, the Flingern RPP received a total of $21.7 million in tipping fees. The processing of this refuse resulted in the net generation of 5.8 million tons (5.26 x 10^9 kg) of high pressure, high temperature superheated steam, for which cumulative payment of $20.6 million was received. During the same period, postcombustion materials recovery accounted for the sale of 103,000 tons (9.38 x 10^7 kg) of ferrous scrap and 1,201,600 tons (1.09 x 10^9 kg) of processed ash. Sale of the former earned $2.5 million, and sale of the latter earned $141,200.

It is difficult to deal with the exploitation of investment capital of the Flingern RPP because of the effects which inflation has had on the cost of
<table>
<thead>
<tr>
<th>Type of Power Plant Ownership</th>
<th>Design Capacity</th>
<th>Evaluation Period</th>
<th>Average Capacity Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Fired (1) US Commercial</td>
<td>&gt;100 MW</td>
<td>1961 - 1973</td>
<td>66.9% for N = 250</td>
</tr>
<tr>
<td>Nuclear Fueled (1) US - Wisconsin Electric Power (4)</td>
<td>&gt;450 MW</td>
<td>1968 - 1975</td>
<td>59.3% for N = 38</td>
</tr>
<tr>
<td>Nuclear Fueled (1) US - Commonwealth Edison (5),</td>
<td>&gt;450 MW</td>
<td>1972 - 1975</td>
<td>71.6% for N = 2</td>
</tr>
<tr>
<td>Nuclear Fueled (1) US - Consumer Power</td>
<td>&gt;821 MW</td>
<td>1971 - 1975</td>
<td>53.3% for N = 6</td>
</tr>
<tr>
<td>Nuclear Fueled (1) US - Commonweal th, Edison (5), Chicago, Ill.</td>
<td>&gt;821 MW</td>
<td>1971 - 1975</td>
<td>23.2% for N = 1</td>
</tr>
<tr>
<td>Nuclear Fueled (1) US - Nuclear Power (6)</td>
<td>821 MW</td>
<td>1972 - 1975</td>
<td>51.8% for N = 21</td>
</tr>
<tr>
<td>Nuclear Fueled (1) US - Consumer Power (6)</td>
<td>&gt;450 MW</td>
<td>1968 - 1975</td>
<td>57.5% for N = 7</td>
</tr>
<tr>
<td>Refuse Fired (2) FRG - Municipal and Commercial</td>
<td>&gt;500 STPD</td>
<td>1960 - 1975</td>
<td>65.2% for N = 1</td>
</tr>
<tr>
<td>Refuse Fired (2) FRG - Municipal, Equipped with VGM</td>
<td>&gt;500 STPD</td>
<td>1965 - 1975</td>
<td>80.2% for N = 1</td>
</tr>
<tr>
<td>Refuse Fired (2) FRG - City of Duesseldorf, Dept. of Sanitation</td>
<td>1,400 STPD</td>
<td>1966 - 1975</td>
<td>64.7% for N = 1</td>
</tr>
<tr>
<td>Refuse Fired (2) FRG - City of Offenbach (Regional Solid Waste Authority)</td>
<td>790 STPD</td>
<td>1972 - 1975</td>
<td>64.7% for N = 1</td>
</tr>
<tr>
<td>Refuse Fired (2) FRG - City of Offenbach (Regional Solid Waste Authority)</td>
<td>790 STPD</td>
<td>1972 - 1975</td>
<td>64.7% for N = 1</td>
</tr>
</tbody>
</table>

Notes:
2. "Mueilverbrauchsanlagen in der Bundesrepublik Deutschland" by L. Bartsche, Umweltbundesamt, Berlin 1975
3. Personal Communications with plant operators
4. Best performance of nuclear US utility
5. Largest US nuclear utility
6. Worst performance of nuclear US utility
7. In terms of the plant's primary task, either to generate electricity or to dispose of refuse.
8. Denotes sample size
### TABLE 20 1400 STPD REFUSE POWER PLANT: 11-YEAR OPERATING RESULTS

<table>
<thead>
<tr>
<th>Population Served:</th>
<th>848,000 People (Average 655,000 City Proper, Average 193,000 Other Communities)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Record:</td>
<td>11 Yrs of Continuous Plant Operation (24/24, 7/7, 365/365, or 96,400 Hours)</td>
</tr>
<tr>
<td>Unit Operations:</td>
<td>Boilers #1 - #4 Logged 68,000 - 74,000 Hours through 1-31-77 (Operating on the Average 74% of the Time)</td>
</tr>
<tr>
<td></td>
<td>Boiler #5 Logged 26,000 Hours through 1-31-77 (Operating on the Average 67% of the Time)</td>
</tr>
<tr>
<td>Refuse Processed:</td>
<td>3,196,000 ST (Average Capacity Factor 0.667)</td>
</tr>
<tr>
<td>Steam Produced:</td>
<td>5,775,000 ST (Average Yield Factor 1.81 ST Steam/ST Refuse; Average Capacity Factor 0.591)</td>
</tr>
<tr>
<td>Ferrous Scrap Sold:</td>
<td>103,400 ST</td>
</tr>
<tr>
<td>Ash Processed:</td>
<td>1,201,600 ST</td>
</tr>
<tr>
<td>Ash Sold:</td>
<td>785,300 ST (Varies with Demand by Construction Industry, Average 65% of Production)</td>
</tr>
<tr>
<td>Tipping Fees Collected:</td>
<td>21,695,000 US $ (Average $6.65/ST Refuse)</td>
</tr>
<tr>
<td>Steam Sales Income:</td>
<td>20,616,000 US $ (Average $3.65/ST, or $1.83/1,000 lb Steam)</td>
</tr>
<tr>
<td>Scrap Sales Income:</td>
<td>2,515,000 US $ (Average $22.71/ST Scrap)</td>
</tr>
<tr>
<td>Ash Sales Income:</td>
<td>141,200 US $ (Average $0.19/ST Ash)</td>
</tr>
<tr>
<td>Energy Conservation from Steam Raising:</td>
<td>673,200 ST of Standard Coal, or 113.4 Million Gallons of Medium Sulfur Fuel Oil</td>
</tr>
<tr>
<td>Energy Conservation from Materials Recycling:</td>
<td>110,000 ST of Standard Coal, or 21.5 Million Gallons of Medium Sulfur Fuel Oil</td>
</tr>
<tr>
<td>Total Energy Conservation:</td>
<td>783,200 ST of Standard Coal, or 134.9 Million Gallons of Medium Sulfur Fuel Oil</td>
</tr>
<tr>
<td>Technology Status:</td>
<td>308 Billion Ton-Hours of Cumulative Plant Operating Experience</td>
</tr>
</tbody>
</table>

Primary energy conservation was practiced consistently and on a large scale, resulting in direct savings of 673,000 tons (6.11 x 10^8 kg) of standard coal, or 113.4 million gal (4.29 x 10^5 m^3) of medium sulfur fuel oil, from the application of refuse power. Materials recycling generated additional indirect savings of 110,000 tons (9.98 x 10^7 kg) of coal, or 21.5 million gal (8.14 x 10^4 m^3) of oil. Thus, the total in energy savings can be estimated at 783,000 tons (7.10 x 10^8 kg) of coal, or 134.9 million gal (5.11 x 10^9 m^3) of oil, which does not include the effects of reduced gravel mining resulting from the sale of ash.

### CONCLUSIONS AND RECOMMENDATIONS

The long range trend in RPP operations can be best expressed by referring to the refuse processing and steam generation rate data. From Fig. 6 it can be concluded that RPP operations have attained such a high degree of maturity that major surprises need not be expected in the near future.

As a rule, steam generation showed steady growth; and, if there were any upsets in political life or in the economy of the nation, they certainly failed to affect the operational stability. There were two exceptions to this rule, however, which deserve discussion because they could possibly happen again. Characteristically, both exceptions were only of...
minor consequence, as the steam generation rate resumed its growth in each case without delay. Both exceptions were also softened by concurrent changes in the incoming refuse stream.

The first exception occurred in 1971 and was caused by major equipment modifications and the installation of the fifth processing line. Continued growth in the heating value of refuse took up some of the slack, and in any event, the newly expanded plant capacity permitted steam generation to catch up quickly and surpass the previous high performance mark.

The second exception in 1974 came as a result of the interference of the OPEC cartel with the energy market and the nation’s economy. Its most direct effect was a sharp drop in the heating value of refuse, but this interference was blunted largely by increasing refuse throughput and decreasing refuse bypassing to landfill, a rather simple switch in logistics. In this context, it is important to observe that limited bypassing, while it may not be totally to the liking of the environmentalists, makes good economic sense. Limited bypassing permits full utilization of installed plant capacity and invested capital regardless of any shifts in the size of the contributing population, in the per capita refuse generation rate, or in the heating value of the refuse.

The City of Duesseldorf and the operator of the Flingern RPP have recognized the value of this compromise, and they are now proceeding with procurement and installation of the compactor/baler to enhance this bypassing capability. Unlike boilers, a compactor/baler does not require warm up/cool down or pressurization/depressurization procedures which may take hours or days to accomplish; it stands ready for immediate use. Such a compactor/baler costs less than a boiler system, can be installed quickly, and when serving in the capacity of the transfer station, will prevent the loss of revenues from reduced tipping due to limitations in plant processing capacity. Added benefits of a compactor/baler installation will be the selectivity with which the plant operator can direct certain refuse loads, either to the boilers or to the landfill, and the ease with which he could accommodate seasonal peaks in the flow of refuse. Also, the judicious operation of the transfer station will avoid the occurrence of a refuse shortage, no matter how rare one may be. Drastic changes are not expected in this regard, because of the close control which is presently being exercised by the operator over steam generation. The effect of this control is evidenced by the closeness of the SSR actual, 2.07, to SSR design, 2.09, another measure of successful RPP operation within existing constraints.

Linear regression analysis indicates with a high degree of confidence that heating values can be expected to continue to rise in Duesseldorf. While heating values may not approach those of Stockholm, Sweden or the United States in the foreseeable future, the increase in heating values will, regrettably, reduce the annual tonnage of refuse that may be converted to steam, unless additional boiler capacity is added.

The new and larger boiler has already been designed for installation in the sixth processing line. With a SSR of 3.20, this boiler falls into the modern class (SSR = 3.00 to 3.30), which is required for new applications in the urban areas of Europe and North America. Unfortunately, this new boiler will require at least two years for its procurement and installation and yet another year for start up and testing, so at least three years will pass before it will fully affect plant performance. Even then, the average plant SSR will only show a marginal improvement by going over the present 2.09 SSR to the future 2.30 SSR, which means that a 10 percent increase in SSR would coincide with an estimated 5 percent to 8 percent increase in heating value. One welcome side effect of installing the sixth boiler will be the improved use of energy within the plant itself, since all groups of auxiliaries will then be fully loaded. Specific energy consumption is expected to either hold at 44 kWh/ton (4.85 x 10^{-2} kWh/kg) on refuse, or to decline slightly to approximately 40 kWh/ton (4.41 x 10^{-2} kWh/kg).

Because of the aforementioned boiler limitations, the PCF is expected to either remain stationary or to decline gradually for the near term, leaving much of the installed grate capacity unused. Improvements can be attempted in two areas; changes in plant O & M may not be easy, mainly because the Flingern RPP is already ranked at the top of its class. It should be the subject of an appropriate O & M study to determine if down time could be further reduced by equipment modification and operational revisions. It is conceivable that it might be advantageous to perform all maintenance work around the clock and pay the necessary wage differentials in order to avoid a loss in revenues resulting from prolonged down time. Another approach could be the shift towards preferentially accepting wastes with lower heating values in order to keep up plant throughput and tipping fee collections. This approach would hardly be worthwhile because additional moisture would need to be vaporized, thus reduc-
FIG. 6 1400 STPD REFUSE POWER PLANT: MAJOR PERFORMANCE PARAMETERS
ing existing boiler efficiencies.

Replacing the initial boilers, Units 1 through 4, with new and larger units is possible, but it is also difficult and expensive because of space limitations. Eventually a point may be reached when a new plant becomes necessary. A separate planning study will be required to determine when this will occur, but again, it is to the credit of the city fathers and the plant operator that a site has already been designated for the new Flügern RPP II. Since the site is currently a sports field adjacent to the western boundary of the existing RPP, a new and larger boiler house can be built without interfering with present operations at the Flügern RPP I or with the Flügern EPS. Besides the timing for new construction, this planning study needs to determine the optimum in terms of numbers and sizes of units to be installed, and, perhaps most importantly, answer the question as to whether or not the incremental approach to equipment installation should be followed again.

In closing, it should be pointed out that during 96,400 hr of continued plant operations, the Flügern RPP has neither shut down nor failed to fulfill its primary responsibility, which is to provide the City of Duesseldorf and its neighboring municipalities with a dependable and safe method of waste disposal. The Flügern RPP has been accepted as a good neighbor without the problems of vermin, odor, or deadly methane gas often associated with waste disposal methods such as landfill.

The authors have gone to some length in presenting what they believe to be the true significance of the Flügern story in the hope that it will inspire other operators to publish their experiences. The cause of refuse power could be best advanced by providing a cohesive and diversified data base which documents the extraordinary success of this technology.

**REFERENCES**


**Key Words:** Boiler, Bulky Waste, Combustion, Energy, Fuel, Germany, Incineration, Power, Waterwall
Discussion by

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This paper may certainly be considered as an important contribution to the literature in the general area of solid waste and, more specifically, in the waste-to-energy field. In the paper, Klaus Feindler and Karl Thoeman have comprehensively summarized the significant conclusions which can be drawn from the experiences of the Duesseldorf refuse-fired boiler plant.

The information, presented impressively, documents the economic, environmental and energy-related contributions of the Flingern Plant. Also, and quite modestly put, one finds an equally impressive testimonial to the significant personal and technical achievements of the plant management, engineering and operating staff. Of special meaning to most of those attending this conference, the paper states in unarguable terms that large-scale energy recovery from burning mixed municipal solid waste is, indeed, the state-of-the art. This point is forcefully brought home not only for the Flingern plant, which is the focus of interest, but also for several other plants, grate systems and boilers.

Because the paper deals primarily with economic- and capacity-related statistics, I do not have any major technical questions. I would ask, however, for the authors’ opinion as to the effect of evaluating the plant capacity factor on a Btu rather than a tonnage basis. Although one recognizes that the municipal government looks to a refuse incinerator as a mass disposal system, a fairer measure of its reliability and utility might better be made by using the system’s basic design measure: heat release.