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Refuse and Coal Fired Boilers Team Up at Duesseldorf To Cogenerate Electricity and District Heat

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Abstract

The Duesseldorf Refuse Power Plant (RPP) has recently been expanded once again to further enhance energy and materials recovery from refuse. New design features which distinctly depart from the equipment previously installed are described. Statistical data is presented which supersedes previous publications in order to establish a continuous 17-year operating record. Integration of the RPP with a conventional coal fired cogeneration plant is discussed, together with an estimate of the amount of primary energy which has been conserved by substituting refuse for coal.

Introduction

The successful long-term operating record of the Duesseldorf Refuse Power Plant (RPP) has previously been discussed in several papers [1, 2]. However, little has been said in the past as to how the energy recovered from refuse is marketed. In fact, unlike some other waste-to-energy projects, the Duesseldorf RPP does not market its energy output directly. Instead, the RPP is closely coupled with the Flingern Cogeneration Station (FCS) where its refuse derived steam is mixed with coal derived steam in a common header. In the end, it is the FCS which operates a complex system of turbines and heat exchangers from which the final output in the form of electricity, hot water and steam is marketed. The subject paper is to serve a threefold purpose:

(1) To update the RPP’s major operating statistics beyond what has already been published.

(2) To summarize important design changes which were made during the last plant expansion.

(3) To describe integration of the RPP into the Flingern Energy Complex and estimate its impact on the City’s energy market.

Statistical Data Update

Table 1 presents the major plant operating parameters on a 17-year basis: Waste disposal, energy consumption, energy recovery, ferrous scrap recovery. Figure 1 shows the same data in the form of trend lines.

Inspection of both Table 1 and Figure 1 leads to the same conclusion that final plant expansion in 1980 caused a dramatic change.

Prior to 1980, a leveling off was observed for all parameters, i.e. 305,000 short tons per year (STPY) (2.77 x 10^8 kg per year) of refuse processed, 15,000 MWh of electricity consumed, 650,000 STPY (5.91 x 10^8 kg per year) of ferrous scrap sold and 100,000 STPY (9.09 x 10^7 kg per year) of raw ash produced.

After 1980, with the help of the new and sixth processing line, all major operating parameters resumed their growth. Although it is too early to make a firm prognosis, it appears to be safe to predict that a new performance plateau may be reached in the next few years: 400,000 STPY (3.63 x 10^8 kg per year) of refuse processed and 900,000 STPY (8.18 x 10^8 kg per year) of steam exported. Of course, this will depend on stable population levels and undiminished per-capita waste generation rates.

Specific or derived performance parameters are listed in Table 2. Of these, the nearly continuous rise of the lower heating value is significant. Two temporary depressions, one in 1974 and the other 1981, can be related to adverse developments in the national economy. The first was the result of OPEC, while the second coincided with the economic recession. While it is possible that the heating value may rise once again, its unlimited growth is rather unlikely. In all probability, stabilization is expected at a lower heating value, or LHV of 3,700 Btu/Lb. The corresponding higher heating value, or HHV, can be obtained by using the following approximation: HHV = LHV + 570 (Btu/Lb). The resultant HHV = 4,270 Btu/Lb approaches that of some American municipalities.

For a given boiler design, the boiler thermal efficiency is largely based on lower heating value of the refuse fired. This efficiency experienced a modest improvement over the years, which can be traced to two factors: increased heating value of refuse and improved boiler operation. Additional improvements beyond the present level are not expected.

The specific steaming rate flattened out at about 2.15 ST/ST (2.15 kg/kg), i.e. a value which is close to the design value of 2.25 ST/ST (2.25 kg/kg). The latter is the average for all six processing lines combined.

Limited boiler capacity was the main reason for bypassing waste to the landfill in years past. For example, a total of 420,133 ST (3.81 x 10^8 kg) of processible solid waste was collected in the Duesseldorf service area during 1980. Because of capacity limitations in
Table 1:  

<table>
<thead>
<tr>
<th>Operating Year</th>
<th>Refuse Processed</th>
<th>Electricity Bought</th>
<th>Ferrous Scrap Separated</th>
<th>Metal Recovery</th>
<th>Ash Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>224</td>
<td>7,927</td>
<td>356 327</td>
<td>8.10</td>
<td>—</td>
</tr>
<tr>
<td>1967</td>
<td>260</td>
<td>8,315</td>
<td>405 393</td>
<td>9.60</td>
<td>0.35</td>
</tr>
<tr>
<td>1968</td>
<td>262</td>
<td>8,736</td>
<td>470 435</td>
<td>9.36</td>
<td>0.42</td>
</tr>
<tr>
<td>1969</td>
<td>290</td>
<td>9,242</td>
<td>495 465</td>
<td>9.35</td>
<td>0.57</td>
</tr>
<tr>
<td>1970</td>
<td>290</td>
<td>9,477</td>
<td>512 471</td>
<td>9.09</td>
<td>0.74</td>
</tr>
<tr>
<td>1971</td>
<td>267</td>
<td>9,420</td>
<td>500 469</td>
<td>8.90</td>
<td>0.95</td>
</tr>
<tr>
<td>1972(10)</td>
<td>295</td>
<td>12,210</td>
<td>567 534</td>
<td>9.24</td>
<td>0.97</td>
</tr>
<tr>
<td>1973</td>
<td>318</td>
<td>13,955</td>
<td>593 564</td>
<td>10.32</td>
<td>0.62</td>
</tr>
<tr>
<td>1974</td>
<td>325</td>
<td>14,143</td>
<td>572 542</td>
<td>9.95</td>
<td>0.56</td>
</tr>
<tr>
<td>1975</td>
<td>327</td>
<td>14,107</td>
<td>650 616</td>
<td>10.10</td>
<td>0.61</td>
</tr>
<tr>
<td>1976</td>
<td>315</td>
<td>14,521</td>
<td>652 621</td>
<td>9.39</td>
<td>0.59</td>
</tr>
<tr>
<td>1977</td>
<td>315</td>
<td>14,563</td>
<td>654 624</td>
<td>6.22</td>
<td>0.57</td>
</tr>
<tr>
<td>1978</td>
<td>303</td>
<td>14,752</td>
<td>649 618</td>
<td>8.75</td>
<td>0.42</td>
</tr>
<tr>
<td>1979</td>
<td>304</td>
<td>15,027</td>
<td>646 615</td>
<td>10.26</td>
<td>0.31</td>
</tr>
<tr>
<td>1980(11)</td>
<td>300</td>
<td>15,910</td>
<td>636 599</td>
<td>10.15</td>
<td>0.34</td>
</tr>
<tr>
<td>1981</td>
<td>362</td>
<td>19,476</td>
<td>793 751</td>
<td>12.17</td>
<td>0.35</td>
</tr>
<tr>
<td>1982</td>
<td>394</td>
<td>20,953</td>
<td>851 808</td>
<td>11.83</td>
<td>0.40</td>
</tr>
<tr>
<td>17-Year Totals</td>
<td>5,174</td>
<td>202,115</td>
<td>10,004 9,452</td>
<td>164.57</td>
<td>8.37</td>
</tr>
<tr>
<td>17-Year Averages</td>
<td>304</td>
<td>11,559</td>
<td>555 556</td>
<td>9.70</td>
<td>0.49</td>
</tr>
<tr>
<td>17-Year Changes</td>
<td></td>
<td></td>
<td></td>
<td>+75.9%</td>
<td>+164.3%</td>
</tr>
</tbody>
</table>

NOTES:  
(1) Installed processing capacity in short tons of mixed municipal refuse per day when operating continuously; synonymous with nameplate capacity.  
(2) Data Base: EDP summaries consolidated into annual report which is submitted by operator to the owner in June each year.  
(3) 1.0 HT = 1.1 ST was used for conversion.  
(4) Except for electricity which is expressed in Mwh.  
(5) Fully corrected tonnages of combustible waste actually processed. During certain years, total tonnages collected and delivered were higher because insufficient plant capacity necessitated occasional bypassing to a landfill site. Also, some waste was removed for compaction and baling as part of a federally funded research project.  
(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" with 1,209 psia and 923°F.  
(9) Post-incineration ferrous scrap is included.  
(10) Fifth processing line installed, started operating August 1972.  
(11) Sixth processing line installed, started operating October 1980.

existence at the time only 71.4 percent could be processed by the RPP, while the remainder, or 28.6 percent had to be bypassed to the landfill. This bottleneck should be relieved by the effectiveness of the new sixth line as well as by continued upgradings of the older units. This contention is supported by the fact that already 394,000 ST (3.58 x 10⁸ kg) of waste were processed by the RPP during the most recent year.

Careful inspection of Table 2 reveals that with the increase in heating value there has been a reduction in the ash generation rate, which may be related to changes in the composition of refuse, i.e., more combustibles and less inerts. A commensurate decrease in the density of refuse has been observed by the Düsseldorf Department of Sanitation (see [1]). However, during the most recent years, a new increase is noted in the ash generation rate, because the solids generated by the new flue gas scrubbing system are added to the ash for disposal.

Specific electrical power consumption appears to have stabilized at about 54 kWh/ST (59.4 kWh per 10³ kg). It is conceivable that a small increase may come about in the future when all processing lines will be equipped with acid gas scrubbers, as mandated by regulatory requirements (see [3]). Other increases are largely due to the installation of larger pumps and blowers which require more power when idling. Also, the installation of a shredder for bulky waste reduction in 1972 had lead to an earlier boost in electrical consumption.

Specific water consumption does not seem to exhibit any particular trend except that during the 1977 to
Figure 1
Duesseldorf RPP Performance Trends
### Table 2:

1,730 STPD, Refuse Power Plant: Major Performance Parameters

<table>
<thead>
<tr>
<th>Year</th>
<th>Lower Heating Value (Btu/Lb)</th>
<th>Boiler Thermal Efficiency</th>
<th>Specific Steaming Rate</th>
<th>Steam Conformance Factor</th>
<th>Specific Ash Rate</th>
<th>Specific Electrical Power Consumption</th>
<th>Specific Oil Consumption</th>
<th>Specific Water Consumption</th>
<th>Equipment Utilization Factor</th>
<th>Capacity Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>2,468</td>
<td>69.1</td>
<td>1.59</td>
<td>0.919</td>
<td>0.432</td>
<td>35.4</td>
<td>(1.570)</td>
<td>566</td>
<td>0.729</td>
<td>0.551</td>
</tr>
<tr>
<td>1967</td>
<td>2,621</td>
<td>68.8</td>
<td>1.61</td>
<td>0.963</td>
<td>0.414</td>
<td>32.1</td>
<td>(0.292)</td>
<td>267</td>
<td>0.742</td>
<td>0.672</td>
</tr>
<tr>
<td>1968</td>
<td>2,792</td>
<td>68.6</td>
<td>1.67</td>
<td>0.926</td>
<td>0.446</td>
<td>31.0</td>
<td>(0.093)</td>
<td>432</td>
<td>0.735</td>
<td>0.732</td>
</tr>
<tr>
<td>1969</td>
<td>2,982</td>
<td>68.4</td>
<td>1.71</td>
<td>0.939</td>
<td>0.437</td>
<td>31.9</td>
<td>0.011</td>
<td>471</td>
<td>0.786</td>
<td>0.752</td>
</tr>
<tr>
<td>1970</td>
<td>2,948</td>
<td>68.6</td>
<td>1.82</td>
<td>0.920</td>
<td>0.442</td>
<td>33.6</td>
<td>0.004</td>
<td>409</td>
<td>0.764</td>
<td>0.732</td>
</tr>
<tr>
<td>1971</td>
<td>3,087</td>
<td>69.5</td>
<td>1.87</td>
<td>0.938</td>
<td>0.399</td>
<td>35.3</td>
<td>0.019</td>
<td>501</td>
<td>0.776</td>
<td>0.693</td>
</tr>
<tr>
<td>1972</td>
<td>3,164</td>
<td>69.9</td>
<td>1.94</td>
<td>0.942</td>
<td>0.372</td>
<td>41.7</td>
<td>0.003</td>
<td>462</td>
<td>0.773</td>
<td>0.743</td>
</tr>
<tr>
<td>1973</td>
<td>3,037</td>
<td>70.8</td>
<td>1.86</td>
<td>0.951</td>
<td>0.392</td>
<td>43.9</td>
<td>0.011</td>
<td>574</td>
<td>0.653</td>
<td>0.626</td>
</tr>
<tr>
<td>1974</td>
<td>2,857</td>
<td>69.2</td>
<td>1.74</td>
<td>0.948</td>
<td>0.380</td>
<td>43.1</td>
<td>0.011</td>
<td>724</td>
<td>0.715</td>
<td>0.644</td>
</tr>
<tr>
<td>1975</td>
<td>3,147</td>
<td>72.3</td>
<td>1.99</td>
<td>0.948</td>
<td>0.386</td>
<td>43.1</td>
<td>0.011</td>
<td>509</td>
<td>0.707</td>
<td>0.618</td>
</tr>
<tr>
<td>1976</td>
<td>3,247</td>
<td>73.1</td>
<td>2.07</td>
<td>0.952</td>
<td>0.371</td>
<td>46.2</td>
<td>0.003</td>
<td>592</td>
<td>0.727</td>
<td>0.621</td>
</tr>
<tr>
<td>1977</td>
<td>3,251</td>
<td>73.3</td>
<td>2.06</td>
<td>0.954</td>
<td>0.348</td>
<td>47.3</td>
<td>0.018</td>
<td>592</td>
<td>0.727</td>
<td>0.621</td>
</tr>
<tr>
<td>1978</td>
<td>3,397</td>
<td>73.2</td>
<td>2.14</td>
<td>0.952</td>
<td>0.308</td>
<td>48.8</td>
<td>0.005</td>
<td>528</td>
<td>0.730</td>
<td>0.596</td>
</tr>
<tr>
<td>1979</td>
<td>3,522</td>
<td>72.4</td>
<td>2.13</td>
<td>0.952</td>
<td>0.304</td>
<td>49.4</td>
<td>0.003</td>
<td>464</td>
<td>0.740</td>
<td>0.595</td>
</tr>
<tr>
<td>1980</td>
<td>3,673</td>
<td>71.3</td>
<td>2.12</td>
<td>0.942</td>
<td>0.344</td>
<td>53.0</td>
<td>0.029</td>
<td>384</td>
<td>0.645</td>
<td>0.596</td>
</tr>
<tr>
<td>1981</td>
<td>3,403</td>
<td>75.0</td>
<td>2.19</td>
<td>0.947</td>
<td>0.352</td>
<td>53.8</td>
<td>0.017</td>
<td>295</td>
<td>0.663</td>
<td>0.573</td>
</tr>
<tr>
<td>1982</td>
<td>3,413</td>
<td>74.0</td>
<td>2.16</td>
<td>0.949</td>
<td>0.362</td>
<td>53.2</td>
<td>0.000</td>
<td>534</td>
<td>0.699</td>
<td>0.624</td>
</tr>
</tbody>
</table>

#### 17-Year Statistics

- **MIN.**: 2,465 Btu/Lb, 68.4% Efficiency, 0.308 ST/ST, 31.0 gal/ST
- **AVG.**: 3,113 Btu/Lb, 71.0% Efficiency, 0.308 ST/ST, 31.0 gal/ST
- **MAX.** 3,673 Btu/Lb, 75.0% Efficiency, 0.308 ST/ST, 31.0 gal/ST
- **C.V.** ±38.3% ±9.3% ±31.8% ±4.7% ±36.1% ±53.6% ±263.6% ±116.1% ±21.4% ±27.5% ±34.1%

**NOTES:**

1. Computations from Table 1 and EDP readouts from the plant operator's annual report.
2. Approximate conversions can be made by using the relationship: \( LHV = HHV - 1,040 \text{ (w)} \) with \( LHV \) = Lower Heating Value of Refuse in \( \text{Btu/lb} \), \( HHV \) = Higher Heating Value of Refuse in \( \text{Btu/lb} \), \( w \) = Water Content of Refuse \( \text{lb/lb} \), both free water and chemical water, and 1,040 = Conversion Factor, Assuming \( w = 0.55 = \text{constant}, HHV = LHV + 572.
3. Actual tons of steam generated per ton of refuse processed in (ST/ST), i.e., the "supply" tons which refer to indicated gauge pressure and temperature.
4. The ratio of "accounting" tons to "supply" tons whereby the "accounting" tons represent the amount of steam adjusted to fixed reference conditions of pressure and temperature (1,209 psia and 923°F).
5. Ferrous scrap and moisture content of approximately 15% by weight are included.
6. For start-up and stand-by operations. The first three years are excluded from statistical treatment because of their atypical nature.
7. Cumulative annual operating hours for all processing lines divided by the number of lines installed and the factor of 8,760 hours.
8. Actual tons of refuse processed divided by the plant's daily nameplate capacity and the factor of 365 days.
9. Actual tons of steam generated divided by the plant's daily nameplate capacity and the factor of 365 days.
10. Heavy construction: completion of #6 processing line, modification of #5 boiler. Additional scrubber.
11. Arithmetic average for 17-year period calculated as:

\[
\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{52}{17} = 3.058
\]

12. Percentage change over 17-year period calculated as:

\[
\frac{\bar{x}_{17} - \bar{x}_{66}}{\bar{x}_{66}} \times 100 = \frac{3.058 - 2.66}{2.66} \times 100 = 14.71\%
\]

13. Coefficient of variability for 17-year period calculated as:

\[
\text{C.V.} = \frac{\text{MAX} - \text{AVG}}{\text{AVG}} \times 100 = \frac{3.058 - 2.66}{2.66} \times 100 = 14.71\%
\]

1981 period there was a steady decrease. During 1982 this trend stopped and there was a significant increase. Of course, it takes only one major defective valve to severely upset the flow of water in and out of the quench tanks. Consequently, other fluctuations are likely to occur in the future.
### Table 3
Statistical Data Summary
As of December 31, 1982

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Operating Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Record:</td>
<td>17 years of continuous plant operation (24/24; 7/7; 365/365 or 148,920 hours)</td>
</tr>
<tr>
<td>Unit Operations:</td>
<td>Boilers #1: 110,142&lt;br&gt;Boiler #2: 103,604&lt;br&gt;Boiler #3: 110,133&lt;br&gt;Boiler #4: 112,497&lt;br&gt;Boiler #5: 55,525&lt;br&gt;Boiler #6: 16,204</td>
</tr>
<tr>
<td>All Boilers Combined:</td>
<td>508,105 hours</td>
</tr>
<tr>
<td>Refuse Processed:</td>
<td>5,174,000 ST (Average Grate Capacity Factor 0.650) (4.71 x 10^8 kg)</td>
</tr>
<tr>
<td>Steam Produced:</td>
<td>10,004,000 ST (Average Steaming Rate 1.92 ST Steam/ST Refuse) (9.09 x 10^8 kg); (Average Boiler Capacity Factor 0.593); (1.92 kg Steam/kg Refuse)</td>
</tr>
<tr>
<td>Ferrous Scrap Sold:</td>
<td>173,640 ST (1.57 x 10^8 kg)</td>
</tr>
<tr>
<td>Ash Produced:</td>
<td>1,960,100 ST (1.78 x 10^8 kg)</td>
</tr>
<tr>
<td>Ash Sold:</td>
<td>1,068,600 ST (9.71 x 10^8 kg)</td>
</tr>
<tr>
<td>Energy Conservation from Steam Raising:</td>
<td>1,166,100 ST (10.6 x 10^8 kg) of standard coal, or 196.5 million gallons (7.43 x 10^9 m^3) of medium sulfur fuel oil</td>
</tr>
<tr>
<td>Energy Conservation from Materials Recycling:</td>
<td>184,700 ST (9.68 x 10^8 kg) of standard coal, or 36.1 million gallons (1.36 x 10^9 m^3) of medium sulfur fuel oil.</td>
</tr>
<tr>
<td>Total Energy Conservation:</td>
<td>1,350,800 ST (1.23 x 10^9 kg) of standard coal, or 232.6 million gallons (8.79 x 10^9 m^3) of medium sulfur fuel oil.</td>
</tr>
<tr>
<td>Technology Status:</td>
<td>771 Billion Ton-Hours (7.00 x 10^14 kg-h) of Cumulative Plant Operation Experience (This is the product of plant operating hours and the amount of refuse processed.)</td>
</tr>
</tbody>
</table>

Since about 18 percent of the ash weight is water carried over from the quench tanks, any improvement in ash dewatering should also help to reduce the ash rate. As will be discussed in a later section of this paper, the sixth processing line is equipped with a piston extractor which replaces the more conventional drag chains. In the future, if the older processing lines are retrofitted with piston extractors, there may be some new savings in water consumption. Compared to some other plants, the Duesseldorf RPP has a relatively high water consumption. This is somewhat surprising in view of the fact that condensate and/or make-up water is supplied by the FCS. It may be wise to commission a water conservation study in order to find new ways for reduced consumption.

The equipment utilization factor, i.e., the ratio of actual operating hours to theoretical operating hours remains high at the 0.72 average mark. This is especially true in view of the age and the complexity which characterize the Duesseldorf RPP. Other mitigating circumstances are the conditions of pressure and temperature which are exceptionally high for refuse fired boilers. In fact, they are among the highest for any such a system anywhere in the world (see Ref. [4]). A recent drop-off is believed to be the result of construction activities on one hand and a realignment of refuse supply logistics on the other hand.

The capacity factors for the grates and boilers tend to approach congruency, which indicates successful load matching and a general maturing of plant operations. A perfect match appears to be nearly impossible because of the non-homogeneous nature of refuse as a fuel. New boiler controls, like the ones installed with the sixth processing line, are expected to improve boiler performance by minimizing load swings.

Table 3 summarized the lifetime record of the Duesseldorf RPP through December 31, 1982. Even to those who are skeptical of waste-to-energy conversions as a viable technology, the following numbers must look impressive: during a half million boiler operating hours, 5 million tons of refuse were burned in order to generate 10 million tons of high quality steam. The successful sale of 1 million tons of aggregate for construction purposes plus 170,000 tons of ferrous scrap for
steel making add further to the appeal of resource recovery. Total energy conservation can perhaps be described by drawing an analogy to a coal train about 13,500 cars long which would have been required for recovery. Total energy conservation can perhaps best be characterized by beneficial changes in the nature of refuse, changes which permitted shorter retention times. These changes can be characterized as increased heating value, lower moisture content and less ash from residential coal users. Other contributing factors are the substitution of new packaging materials and the fact that an increasing part of the population has switched from coal stoves to district heating. It is also probably that the industrial and commercial waste components, two potentially high Btu components, will grow further. The adequacy of the 6-roller arrangement for Duesseldorf refuse was first tried with the installation of the fifth line. Since this worked out well, the same arrangement was retained for the sixth line.

A hydraulic feed ram has taken the place of the mechanically driven feed tables. The old feed tables were rather sensitive to fluctuations in refuse density, which hampered efforts to maintain a uniform feed rate. The new hydraulic feed rams, on the other hand, not only provide positive displacement, but they also permit partial compression of less dense refuse during feeding. Also, the hydraulic drive is easier to vary and control. The customary quench tank with drag chain conveyors underneath the roller grate system has been replaced by a new vibratory trough conveyor coupled with a piston extractor. Thus, bottom ash, siftings, fly ash and scrubber residues will be extracted with a minimum loss of quench water. The loss is now approximately 13-16 percent water, compared to 18-22 percent before. Very wet ash tends to interfere with vibratory conveyors downstream of conventional ash extractors and may cause additional problems in the ash processing and materials recovery train. Unlike the old drag chain conveyors which were very susceptible to blockage by large objects such as washing machines and refrigerators, the piston extractors are rugged equipment, quite capable of squashing large objects.

The shape of the furnace chamber has been dramatically altered. The older installations were characterized by counter flow, i.e., the refuse fuel moved downward through the fire zone and the resulting flue gases moved upward. Through a throat section with secondary air injection these flue gases were then admitted to the first pass or radiation shaft of the boiler. As Fig. 2 indicates, this new furnace design features parallel flow, i.e., fuel and gases move in the same direction. Although there is a guide vane at the first pass entrance, there is no discernible throat.

With regard to the new boiler, we need to emphasize that rather severe steam conditions of 1,305 psi (8.98 \times 10^6 Pa or 90 bar) pressure and 932°F (500°C) had to be retained. This was because of the already existing requirements in the nearby Flüngern cogeneration plant, i.e., the immediate energy user. In spite of this handicap, the #6 has already passed the 16,000 hour operating mark (as of March 31, 1983) with a utilization factor in excess of 0.8.

The new boiler no longer features platen superheaters such as those that occupied the radiation shafts in the older units. Instead, the first section of the superheater consists of vertical tubes which occupy the entire second pass.

The second superheater section occupies the entire third pass and the upper part of the fourth pass. The remaining part of the fourth and final pass houses the economizer section. All containment and separation walls are made of tube walls which comprise the steam generator section.

Several other new features have been developed. The new design features a full waterwall configuration. This is accomplished by drawing vertical steam generator tubes all the way down to the bottom headers which are positioned directly above the grate beams. Carbofrax M, or silicon carbide, type refractory brick work is erected around and in between these tubes for a mutually beneficial effect: the refractory retains its slag resistance by cooling and the tubes are protected against corrosion. Carbofrax is a special product of the Carborundum Corporation. It contains over 90 percent of Silicon carbide with a special chemical binder. This refractory is not castable and is only supplied in the form of bricks. Still, in the case of furnace temperatures in excess of 1,650°F (900°C) and flue gas atmospheres with a high moisture content, the Carbofrax refractory tends to "grow," i.e., slag buildup occurs. Therefore, additional protection is provided by means of air jets which are connected to the sec-
Legend:
1 Radiation Shaft (1st Pass) with Evaporator Tubing
2 Refuse Feed Hopper
3 Hydraulic Ram Feeder
4 Secondary Air Jets
5 Grate with 6 Adjustable Speed Rollers
6 Primary Air Ducts and Siftings Hoppers
7 1st Superheater Section (2nd Pass)
8 2nd Superheater Section (3rd Pass)
9 2nd Superheater Section (4th Pass)
10 Economizer Section (4th Pass)
11 Flue Gas Guide Vane
12 Furnace Side Wall with Evaporator Tubing
13 Furnace Back Wall with Access Door with Evaporator Tubing
14 Piston Ash Extractor

NOTE: All containment and separation walls of the various boiler passes are furnished with tubing which makes up the evaporator section.

**Figure 2**
New Boiler Design for Duesseldorf RPP

With a steaming capacity of over 41 stph (3.71 \( \times \) \( 10^4 \) kg/hr), this new boiler is considerably larger than the older units with 22 stph (2.00 \( \times \) \( 10^4 \) kg/hr)(#1 to #4) and 33 stph (3.00 \( \times \) \( 10^4 \) kg/hr)(#5). It fills up the entire space in the existing boiler house. The grate has a capacity of processing 14 stph (1.25 \( \times \) \( 10^4 \) kg/hr) of refuse which is identical to the capacity of the #5 unit. However, with a specific steaming rate of

\[
\frac{41}{14} = 2.93 \text{ST}
\]

of steam/ST of refuse (kg of steam/kg of refuse), this larger boiler should tolerate additional rises in the heating value of refuse (max. LHV = 4,680 Btu/lb or 10,886 kJ/kg). This latter feature is particularly important because it is expected that most of the shredded bulky waste will be fired in this new boiler. Due to the preponderance of wood, bulky waste generally has an unusually high heating value when compared with residential waste. The main design parameters for this new boiler are listed in Table 4.

While the #6 processing line was being installed, several other important additions were made to the Duesseldorf RPP. Figure 3 shows the updated layout. Accordingly, a large new and fourth electrostatic precipitator was installed between the existing boiler outlet manifold and the existing stack inlet manifold. This manifold arrangement allows for the servicing of any one precipitator out of four at any given time.

Since the commissioning, the Duesseldorf RPP used exclusively precipitators for achieving compliance with existing air pollution control requirements. This changed decisively in 1974 with the promulgation of TA Luft 74, or "Technical Guidelines for Air Pollution Control" by the German EPA (see [3]). In addition to requiring more efficient removal of particulate matter from the effluent flue gases, TA Luft also stipulated the control of acid gases HCl, HF and SO\(_2\). Because precipitators are not suitable for this purpose, other control devices such as scrubbers had to be added to the more recent facilities. Although not actually a law, TA Luft 74 is being used nevertheless throughout Germany as the basis for implementing West Germany’s Federal Clean Air Act. Upon the initiative of the permitting agency, a quasi-dry scrubber type of system was installed at Duesseldorf. Since similar plants may benefit from this particular development, the permitting agency also provided R & D grant monies. While the #6 line had to be equipped for scrubbing immediately, the permitting agency has set December 31, 1983, as the deadline for retrofitting the older lines, #1 to #5, with scrubbers as well. Some further conceptual changes may yet become necessary since TA Luft is being revised and even stricter requirements are expected during 1983.

The present scrubber used an aqueous solution of calcium hydroxide to treat a flue gas flow of 2.83 million ft\(^3\)/hr (80,000 Nm\(^3\)/hr). This solution is sprayed into the flue gas stream, where a chemical reaction takes place, resulting in the formation of fine solids.
Refuse Processing Rate: 13.8 stph (1.25 × 10^4 kg/h)  
Refuse Heating Value: 4,680 Btu/lb (10,886 kJ/kg)  
Grate Type: Duesseldorf Roller Grate System with 6 rollers, each with independently variable drives  
Grate Dimensions:  
Width: 11.5 ft. (3.5m)  
Length: 50.4 ft. (15.38m)  
Projected Surface: 579 sq. ft. (53.83m²)  
Grate Heat Release Rate: 222,360 Btu/sq. ft. – hr  
(Mean) (2.53 × 10^4 kJ/m² – h) or (702 kW/m²)  
Grate Manufacturer: Vereinigte Kesselwerke A.G. (VKW)  
Boiler Steaming Rate: 81,620 lb/hr, or 40.8 stph (3.71 × 10^4 kg/h)  
Specific Steaming Rate: 2.96 lb Steam/lb Refuse (kg Steam/kg Refuse)  
Feedwater Inlet Temperature: 302°F (150°C)  
Superheated Steam Temperature: 932°F (500°C)  
Pressure at Superheater Outlet: 1,305 psi (8.98 × 10^6 Pa) or (90 bar)  
Flue Gas Exit Temperature: 446°F (230°C)  
Boiler Type: 4-pass with natural circulation  
Boiler Manufacturer: Ferdinand Lentges (under VKW license)
and the evaporation of moisture. These solids contain the former acids; they are removed together with other fly ash in the electrostatic precipitator and added to the bottom ash coming off the grate.

Several advantages are expected from this type of scrubber when compared to the wet types:

1. Wastewater treatment problems are minimized or eliminated.
2. Less water soluble solids are generated, thus reducing leachate problems.
3. No reheating of the effluent gases is required in order to avoid visible plumes and condensation in the stack.
4. Calcium hydroxide (i.e., lime) costs about 2.5 times less than sodium hydroxide.

Testing is still in full progress, so that definite results cannot be reported at this writing.

Another important addition was the installation of a third crane of the semi-automated type (automatic travel and positioning, but manual opening and closing of the bucket). This new crane should be advantageous for the control of occasional pit fires. With this installation, the Duesseldorf RPP has now a full complement of three operating cranes and one standby crane. This augmented crane capacity should be able to keep up with increased refuse deliveries during the day shift. This increase is expected as a result of the new boiler capacity.

In addition to the sixth processing line, a new and larger 2,300 ft (700 m) long high pressure steam line has been built in order to beef up the interconnection between the Duesseldorf RPP and the Flingern Cogeneration Station. While redundant to some extent at the present time, this new line will permit a further increase of the steaming capacity in the future.

Also visible from the updated layout, a new storage building and a new repair shop have been added, thus further crowding the already small plot of 7.2 acres (2.91 x 10^4 m^2). When one considers the fact that the sixth line increased nameplate capacity from 1,400 STPD to 1,700 STPD (1.265 x 10^6 kg/day), it becomes immediately clear that refuse storage and vehicular traffic management are of the utmost importance.

(The remainder of this article including “Integration of Refuse and Coal Fired Boilers” and conclusions will be presented in the next issue of District Heating)