Experience After 20,000 Operating Hours
The Mannheim Incinerator

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INTRODUCTION

The decision of the City Council to have an industrial development on Friesenheimer Island forced the existing dump on that island. Since a new dump would have had to be located outside the city limits, another way had to be found for the disposal of the refuse formerly disposed of on the Island.

All investigations found that incineration was the best answer for the City of Mannheim. Sanitary landfill was not possible because of land-area requirements. Composting was not advisable because of the high percentage of industrial refuse in the total refuse, and customers for the end product could not be found.

These were the reasons for incorporating refuse incineration into the heat and power-plant operation required to serve the industrial area planned for the Island.

The following considerations determined the location of the heat and power plant and the incinerator:
(1) a close vicinity to the oil refinery,
(2) a close vicinity to the industry to be supplied with heat, and
(3) no change in distance to the point of disposal for the collection trucks.

The requirements for sanitary disposal of refuse without creation of water and air-pollution problems will not be discussed in detail.

The incinerator had to be capable of burning domestic and industrial refuse with all their variations. The design had to include the burning of used oil, fats, and gasoline even though the volumes were not fully known at the time of the design.

The design for the first-stage construction was based on the following data given a population of 335,000.

<table>
<thead>
<tr>
<th>TYPES OF REFUSE (TONS/YEAR):</th>
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<tbody>
<tr>
<td>Domestic refuse</td>
<td>85,000</td>
</tr>
<tr>
<td>Industrial refuse</td>
<td>50,000</td>
</tr>
<tr>
<td>Bulky refuse</td>
<td>10,000</td>
</tr>
<tr>
<td>Total</td>
<td>145,000</td>
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<table>
<thead>
<tr>
<th>REFUSE COMPOSITION:</th>
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<tbody>
<tr>
<td>Combustible</td>
<td>37 percent (approx.)</td>
</tr>
<tr>
<td>Ash and noncombustible</td>
<td>27 percent</td>
</tr>
<tr>
<td>Moisture</td>
<td>36 percent</td>
</tr>
<tr>
<td>Calorific Value</td>
<td>1500 kcal/kg (approx.)</td>
</tr>
</tbody>
</table>

1 All references to "tons" in this paper are to long tons.

Based on the figures given in Table 1, the average hourly loadings are 16.5 ton/h and 24.6 Gcal/h.

The Heat and Power Plant, Mannheim-North, is a joint venture of two companies. The boiler and generating facilities included in the plant are given in Table 1.
# Table 1

## Variation of Refuse Composition

### Refuse Delivered to Incinerator*

<table>
<thead>
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<tr>
<td>01 Domestic refuse</td>
<td>7543</td>
<td>6833</td>
<td>7775</td>
<td>6972</td>
<td>7397</td>
<td>6867</td>
<td>6418</td>
<td>5313</td>
<td>4143</td>
<td>1515</td>
<td>3654</td>
<td>7435</td>
<td>71865</td>
</tr>
<tr>
<td>02 Market refuse</td>
<td>54</td>
<td>83</td>
<td>98</td>
<td>77</td>
<td>76</td>
<td>70</td>
<td>77</td>
<td>56</td>
<td>59</td>
<td>60</td>
<td>47</td>
<td>61</td>
<td>818</td>
</tr>
<tr>
<td>03 Street sweepings</td>
<td>50</td>
<td>34</td>
<td>38</td>
<td>41</td>
<td>48</td>
<td>47</td>
<td>35</td>
<td>40</td>
<td>41</td>
<td>28</td>
<td>36</td>
<td>38</td>
<td>476</td>
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<tr>
<td>04 Oil-contam. soil</td>
<td>2</td>
<td>14</td>
<td>2</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td>26</td>
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<tr>
<td>A Total 01-04</td>
<td>7647</td>
<td>6952</td>
<td>7925</td>
<td>7092</td>
<td>7521</td>
<td>6984</td>
<td>6530</td>
<td>5409</td>
<td>4243</td>
<td>1603</td>
<td>3737</td>
<td>7560</td>
<td>73203</td>
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<tr>
<td>05 Bulky waste</td>
<td>11</td>
<td>5</td>
<td>5</td>
<td>12</td>
<td>10</td>
<td>9</td>
<td>94</td>
<td>23</td>
<td>18</td>
<td>12</td>
<td>9</td>
<td>7</td>
<td>215</td>
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<tr>
<td>06 Commercial refuse</td>
<td>2523</td>
<td>2405</td>
<td>2321</td>
<td>2368</td>
<td>2147</td>
<td>2329</td>
<td>2117</td>
<td>1382</td>
<td>2271</td>
<td>2614</td>
<td>2402</td>
<td>2701</td>
<td>27580</td>
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<tr>
<td>07 Packaging material</td>
<td>516</td>
<td>459</td>
<td>516</td>
<td>514</td>
<td>477</td>
<td>497</td>
<td>406</td>
<td>527</td>
<td>513</td>
<td>572</td>
<td>467</td>
<td>411</td>
<td>5875</td>
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<tr>
<td>09 Plastics</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>10</td>
<td>6</td>
<td>19</td>
<td>70</td>
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<tr>
<td>10 Textile</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>1</td>
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<td>24</td>
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<tr>
<td>11 Rubber</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>68</td>
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<tr>
<td>12 Rakings (yard. ref.)</td>
<td>18</td>
<td>18</td>
<td>17</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>14</td>
<td>33</td>
<td>22</td>
<td>26</td>
<td>18</td>
<td>24</td>
<td>232</td>
</tr>
<tr>
<td>13 Solvents, cleaners etc.</td>
<td>2</td>
<td>20</td>
<td>15</td>
<td>18</td>
<td>23</td>
<td>16</td>
<td>16</td>
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<td>16</td>
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<tr>
<td>B Total 05-14</td>
<td>3076</td>
<td>2897</td>
<td>2886</td>
<td>2933</td>
<td>2679</td>
<td>2892</td>
<td>2654</td>
<td>1994</td>
<td>2856</td>
<td>3259</td>
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<td>34239</td>
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<tr>
<td>60 Used Oil</td>
<td>4</td>
<td>8</td>
<td>1</td>
<td>5</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>8</td>
<td>7</td>
<td>27</td>
<td>16</td>
<td>3</td>
<td>92</td>
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<tr>
<td>61 Gasoline</td>
<td>2</td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>C Total 01-60</td>
<td>10727</td>
<td>9857</td>
<td>10812</td>
<td>10030</td>
<td>10210</td>
<td>9880</td>
<td>9186</td>
<td>7411</td>
<td>7106</td>
<td>4889</td>
<td>6676</td>
<td>10753</td>
<td>107537</td>
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### Refuse Delivered to Dump

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<tbody>
<tr>
<td>I Ind. refuse</td>
<td>1650</td>
<td>2755</td>
<td>6545</td>
<td>3914</td>
<td>14864</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II Domestic refuse</td>
<td>1650</td>
<td>2755</td>
<td>6545</td>
<td>3914</td>
<td>14864</td>
<td></td>
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<tr>
<td>D Total I + II</td>
<td>1650</td>
<td>2755</td>
<td>6545</td>
<td>3914</td>
<td>14864</td>
<td></td>
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<tr>
<td>Total C + D</td>
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<td>9857</td>
<td>10812</td>
<td>10030</td>
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### Refuse from dump

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<tbody>
<tr>
<td>Refuse from dump</td>
<td>51</td>
<td>1771</td>
<td>1822</td>
<td></td>
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### Refuse delivered to pit

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</tr>
</thead>
<tbody>
<tr>
<td>Refuse delivered to pit</td>
<td>10727</td>
<td>9857</td>
<td>10812</td>
<td>10030</td>
<td>10210</td>
<td>9880</td>
<td>9186</td>
<td>7411</td>
<td>7106</td>
<td>4889</td>
<td>6727</td>
<td>12524</td>
<td>109359</td>
</tr>
</tbody>
</table>

* Not including small vehicles.
Boilers

<table>
<thead>
<tr>
<th>No. and Type of Unit</th>
<th>Steam Prod. (ton/h)</th>
<th>Steam Temp. (°C)</th>
<th>Steam Press. (a ton)</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 oil-fired</td>
<td>64</td>
<td>525</td>
<td>120</td>
<td>(ERM)</td>
</tr>
<tr>
<td>1 oil-fired</td>
<td>64</td>
<td>525</td>
<td>120</td>
<td>(RNAG)</td>
</tr>
<tr>
<td>1 oil-fired</td>
<td>100</td>
<td>525</td>
<td>120</td>
<td>(RNAG &amp; ERM)</td>
</tr>
<tr>
<td>2 refuse-fired</td>
<td>40</td>
<td>525</td>
<td>120</td>
<td>(RNAG)</td>
</tr>
</tbody>
</table>

Turbo-generators have capacities of 12.5, 2.5, 18.5, and 4.5 MVA.

Reserve units, the water supply, and the water treatment plant are jointly owned. The plant is operated by the Mannheim Power Company. Revisions, repairs, and some design work are also performed by the Power Company. See Figs. 1 and 2 for an aerial view and overall plan of the plant site.

The first-stage construction of the incinerator called for two refuse-fired furnaces. Each furnace was designed to burn the total refuse load, i.e., one unit operating and one unit as a stand-by. Variations from 800 to 2200 kcal/kg in the calorific value for the refuse were anticipated. The refuse pit, with a volume of 3000 m³, was sized for continuous operation during long week ends. The volume was based on a refuse weight of 0.4 tons/m³.

The high ground water elevation forced the refuse-storage facilities to be designed as a combination tip and pile storage pit in place of a deep storage pit. A
hammermill was included in the design for the reduction of bulky refuse. Two cranes with orangepeel buckets were provided for refuse handling.

The specifications for the refuse-fired furnace and boiler called for a refuse-burning grate, a waterwall furnace enclosure, and a natural circulation boiler with auxiliary oil firing. Figure 3 shows a cross section of the furnace and boiler. The units were designed for the following operating conditions:

- Steam production (each boiler): 40 ton/h
- Steam pressure — design: 136 atm
- Steam pressure at boiler discharge: 119 atm
- Steam temperature: 525°C
- Make-up water entrance temperature: 160°C
- Refuse burning rate (each unit):
  - Average — 15 ton/h
  - Maximum — 18 ton/h
- Heat from refuse: 27 Gcal/h

Each of the two refuse-fired boilers has 2.5 passes with the gas exit on top. The boiler structure is designed to support the boiler roof, the electrostatic precipitator, and all wind loadings on the units.

The furnace has a four-step traveling grate. The surface for the grate was developed in the United States for this use. (See Figs. 4 and 5.)

The refuse is fed through a water-cooled hopper onto the first grate. The first grate is mainly a feeding grate. The following three grates are for burning. The first of these grates is mainly for ignition and

Fig. 3 Natural Circulation Boiler with Combined Refuse and Oil Firing

Fig. 4 Traveling Grate Model “M” 3, Grate Area 4700 x 11,000 = 51.7 m²

Fig. 5 View Toward Charging End of Furnace

IDLER SHAFT

DRIVE SHAFT

Fig. 6 Traveling Grate, Model “M” 3 Grate Shafts
the last one for burnout. Each grate has an independent speed control for regulating the thickness of the refuse layer. The individual speed controls can be coupled. The air supply is regulated manually. The construction of the grate surface, which will be discussed later in more detail, was designed for refuse burning. (Fig. 6).

The residue is quenched in a water-filled tank located under the last grate. The quenched residue is moved from this tank by a drag conveyor onto a steel-plate conveyor for transportation to the residue-processing building.

The heating areas consist of a radiation section with wall superheater, a convection section with final superheater, and a convection superheater, water, and air preheater.

The design calls for maintenance of furnace temperatures at the exit of the combustion chamber at 1050°C and control of temperature variations within acceptable limits through gas recirculation or the firing of auxiliary oil burners. Refuse with a calorific value of 800 kcal/kg and a boiler load of 80 percent requires auxiliary oil firing to maintain the design steam temperature. Air is preheated to 240°C in a corrugated-plate air preheater.

Furnace and boiler are designed to make oil firing only possible. However, the grates have to be covered for this operation. The auxiliary oil burners are located in the radiation section of the furnace.

The plant began to operate in November 1965. Refuse furnace and boiler Unit No. 1 has 14,430 operating hours, and Unit No. 2 has 13,662 operating hours. The total volume of refuse burnt since startup is 302,000 tons. Experience gathered in operating the plant since startup will be discussed in the following sections of this paper.

OPERATING EXPERIENCE

Refuse Pit and Hammermill

Refuse is stored in the 3000 m³ refuse pit by piling it 5 to 6 m higher on the rear wall of the pit than on the tipping edge. In an emergency, gates can be closed at some of the tipping positions, and the refuse can be piled to the top of the gates. This increases the storage capacity of the pit to 4500 m³.

When the refuse is piled to the top of the gates, the refuse density is increased to the originally assumed density of 0.40 ton/m³. The density of fresh refuse when tipped is about 0.21 ton/m³ for domestic refuse and about 0.17 ton/m³ for industrial refuse.

No major interruptions in operation were experienced due to delivery, mixing, reduction of bulky refuse, piling, and furnace feeding. One exception was the bulky-refuse operation in 1966. During that year, the City collected, as in prior years, all the bulky refuse in the City in 1 month and tried to burn it with the normally collected refuse. But, even though the bulky refuse was reduced in size in the hammermill, the density of the mixed refuse was so low that major backfires occurred in the feeding facilities, causing damage to the hoppers.

Cranes

The two refuse cranes have been operated about 12,500 and 11,000 h, respectively, and have not caused any complaints. The life span of the cables for the polyp-type grapple was about 400 h in the beginning. The life span of the cables was raised to 900 to 1200 operating hours by making changes in the grapple, the grapple equalizer bar, and the sheaves. Increasing the life span of the cables still further is presently being discussed with cable suppliers and manufacturers.

The two cranes are equipped with weighing devices. The polyp-type grapples have a capacity of 6 m³. Operating cycles of the cranes are:

- Clearing the gates and mixing of refuse: 1.0 min
- Clearing the gates and feeding the hammermill with industrial refuse: 2.5 min
- Clearing the gates and mixing of the refuse delivered by city collection vehicles: 1.5 min
- Mixing of the chopped refuse: 1.5 min
- Feeding the furnace with mixed refuse: 2.5 min

It can be seen that the domestic refuse is handled twice and the industrial refuse, three times before being fed to the furnace. The explanation for this procedure is the tipping pattern. Domestic refuse is tipped in Gates No. 6 and 11; industrial and commercial refuse is tipped in Gates No. 3, 4, and 5; the city collection trucks tip in Gates No. 1 and 2. This tipping pattern was chosen to assure separation of domestic and industrial refuse prior to the chopping of the industrial refuse. This pattern of tipping, mixing, and feeding was planned before plant startup and been very successful. Interruptions in the feeding have been infrequent.

The daily refuse volumes for August 1967 and August 1968 are shown in Figs. 7 and 8.
Refuse Composition

Only a few companies deliver pure industrial refuse. The volume of industrial and commercial refuse is about 30 to 35 percent of the total refuse delivered to the plant.

Sampling over a 2-week period in the spring of 1966 showed that about 3 to 5 percent of the total refuse, or about 10 percent of the industrial and commercial refuse, required special attention. The refuse requiring special attention was temporarily taken to a dump.

For the duration of the sampling, this amounted to:
- 22 tons of PVC strips in bale form
- 60 tons of rubber mats and PVC material
- 25 tons of rubber and PVC in cable form
- 18 tons of waxpaper and tinfoil
- 12 tons of PVC and tinfoil in rolls
- 8 tons of cork dust

An agreement with industry for a programmed delivery, supported by publication in the Newsletter of the Chamber of Commerce, has resulted in limiting the refuse transferred directly to the dump to 0.5 to 1 percent of the total delivered to the plant. The refuse presently taken to the dump consists mainly of paper with a metal and mica cover and of PVC in bale form. PVC in bale form cannot be chopped and consequently cannot be mixed with the other refuse.

The following is an excerpt from the agreement published in the Chamber of Commerce Newsletter dated February 1, 1967.

Incineration

a) It is necessary that suppliers of industrial refuse with a composition unknown to the operators of the Incinerator have samples tested by the incinerator operators prior to dumping. The incinerator personnel will, based on experience, pinpoint materials which can cause damage to the incinerator.

b) Refuse with a high calorific value can only be burned after being mixed with domestic refuse. For this reason, suppliers of such refuse are requested to call the incinerator operator prior to dumping to inquire whether the incinerator can accept such refuse at that time.

This applies especially for:
- plastics, plastic covered paper,
- rubber, textiles,
- wood, bark sawdust,
- fats, heavy oil,
- wax, organic material,
- solvents, paint residue,
- residue from pharmaceutical manufacturing plants, gasoline, oil from separators, used oils.

c) The materials mentioned in paragraph b) will only be accepted if they don't exceed the following sizes and weights:
- Plastic 150 kg/vehicle
- Rubber Cable in lengths not to exceed 1 m
- Rubber Mats max. size 0.50 m^2
- Truck and other big tires to be cut in 4 sections
- Fats, heavy oils, wax, solvents
- and paints in cans not exceeding 20 kg.

d) Since the incinerator only accepts combustible material, it is recommended that companies intending to deliver such material should store the combustible and noncombustible material separately.
The volumes of refuse accepted between January 1966 and September 1968 are shown in Fig. 9. The composition of the delivered refuse is shown in Table 2.

Furnace

The first problems occurred in the furnace feeding. The refuse slid through the feeding sections, causing overfeeding of the ignition grate. The consequences were extreme variations in the furnace temperature and steam production, which at some times exceeded the setting of the relief valves and resulted in the wasting of steam through the relief valves. Also, the combustion air could not penetrate through the refuse layer, which caused short circuiting of air between the individual grates and grate hoppers (see Fig. 3). This in turn caused overheating and consequent warping of the grate construction.

The problem of regulating the feeding rate was successfully accomplished by decreasing the size of the feed-hopper exit. This decreased the thickness of the refuse layer discharged onto the first grate from 1.6 to 0.90 m. The speed of the feeding grate was increased, and the refuse was charged through the smaller opening.

There were several results of the change. Sliding of the refuse past the feeding grate was stopped. The thickness of the refuse layer on the feeding grate was decreased, permitting the feeding of the ignition grate with smaller quantities of refuse, but at a more uniform rate. Variations in steam production were limited to ±20 percent, and short circuiting of air was almost completely eliminated.

However, the problems with the grates persisted, at times causing a complete shutdown of plant operation. The reason for this problem was the design of the grate bars, which were not suited for our purposes.
Insufficient cooling of the ends of the grate bars caused wastage of metal to an extent that holes developed in the grates. Measurements and flow tests led to a redesign of the grate bars (see Figs. 10, 11, and 12).

Also, the grate material for Grates No. 2 and 3 was replaced by a material with a higher chromium content.

The "Rostabtrager'' chains and bolts were exchanged for reinforced units of better quality. The short circuiting of air between the grates was corrected by splitting the combined air box into sections serving each individual grate. This also permitted the control of the air supply to each grate. Metering devices were installed in the grate air supply for volume control. Siftings-removal facilities were installed at the turning shafts of the grates for removal of foreign substances in the grates.

The changes were made in the fall of 1967, and no major problems with respect to the grates have occurred since then. We are presently working on an automatic siftings-removal system.

**Boiler Metal Wastage**

Figure 13 shows the number of interruptions in operation due to leaks in the boiler. The leaks were caused by metal wastage due to the combustion gases. The intensity of the metal wastage is influenced by certain conditions, the most important of which is perhaps removal of the protective cover deposited on the tubes by the flue gases.

Bursting of tubes in the combustion chamber was caused by metal wastage on the fire side (57 x 4.5 St. 35.8). The main metal-wastage areas were located through ultrasonic testing. The tubes located in these areas were replaced with studded tubes, which were then lined with plastic refractory. Measurements still show metal wastage, but at a lesser rate (8000 operating hours as compared to 3000 h prior to the changes.) The basis of evaluation for tube replacement was when the tube thickness reached a safety factor of 1.4. Water cleaning increases the corrosion (see Fig. 14).

Tube failures in the final superheater at first occurred infrequently but then at an increasing rate in the beginning of 1967. These failures occurred always in the same place, the tube bends in the superheater. Measurements of the gas velocity showed velocities up to 16 m/sec (Fig. 15). Continuous erosion of the protective coating was the result of...
the high gas velocity. (Shot cleaning has the same effect).

It is known to operators of German incinerator-boiler plants that metal wastage in the superheaters occurred in almost every incinerator in the beginning (1965/66). Thereupon tests were conducted with probes. The results showed that the corrosion of a clean tube with an average wall temperature of 530°C is so extreme that the expected life span of the tube in the superheater is only 3000 h. The same tests showed a reduction in the rate of corrosion with the accumulation of a hard coating on the tubes. (See Refs. [3, 4, and 5] for a discussion of the chemical process of corrosion and composition of deposits on tubes.)

Figures 16 and 17 show the localized nature of this corrosive attack.

We corrected the problems in the superheater by installing deflectors in the combustion chamber and by reducing the gas volume. Damage after 5000 operating hours is not noticeable.

As mentioned at the beginning of the paper, the furnaces are equipped with auxiliary oil-firing equipment permitting operation of the boilers as oil-fired units. The boiler design was based on 150 percent total combustion air.

The plant was originally operated with 160 percent total combustion air, but measurements showed

![Figure 16 NÜ - Bogen, Corrosion - Erosion, Material 10 CrMo 9 10](image)

![Figure 17 Refuse Boiler 2, Final Superheater, Damaged Exterior Tube Ends. 2. Tube Position View from Above](image)

![Figure 18 Refuse Furnace 2, Combustion-Chamber Gas Analysis, Test Plane 1, 10/25/67](image)
the combustion chamber (Figs. 18 and 19). Since then the plant has been operated with 160 to 180 percent total combustion air.

The proportioning of heating areas (preheater, evaporator, and superheater), tightly sized for 150 percent combustion air, did not permit operation at full capacity with the additional combustion air. The result was a derating of the boiler from 27 to 24.3 Gcal. The protective lining of the evaporator tubes increased the deficiency. Consequently, additional evaporator sections were installed in the oil combustion chamber, and a tube wall was installed between the second and third pass in an attempt to improve the proportioning of the heating areas.

The increased air and resulting gas volumes contributed to the damage in the superheater due to high gas velocities. Therefore, a decrease in gas volume was necessary in order to limit velocities to 10 m/sec in a dirty boiler. This required a reduction in the refuse-burning rate with a resulting reduction in the steaming capacity of about 25 percent. This in turn brought the waste gas temperature into the acceptable limit of 230 to 270°C. The compensation for all this was a more satisfactory available operating time.

Control of the combustion-chamber temperature with recirculated flue gas as designed was not practical since the volume of flue gas required to control the buildup of unburned gases with associated areas of reducing atmosphere resulted in very large total gas volumes and, in turn, high velocities.

We have, therefore, arrived at the following mode of operation. About 4.0 m³ combustion air/kg refuse is provided and is not changed. The combustion-chamber temperature is controlled by the refuse-burning rate. This is done by varying the speed of the grates. The travelling grate permits this form of operation.

With a constant rate of feed, we are able to maintain the steam production within ±10 percent with well-mixed refuse without the use of auxiliary oil firing (Fig. 20). Thus, it is possible to have controlled operation in a steam-producing incinerator without auxiliary fuel.

Temperature variations in the combustion chamber caused by bridging in the feed section occur very seldom. In case of bridging, the burner for used-oil disposal is fired for temperature correction.

The monthly heating values based on the daily average are shown in Fig. 21.

**Boiler Cleaning**

As mentioned before, boiler cleaning equipment was not as successful as had been hoped. In fact, the shot cleaning contributed to the corrosion. In our opinion, soot blowers have the same effect. Therefore, we clean the boiler by shaking the heating areas manually. We are planning to install a mechanical vibrator.

The reduction in heat transfer in the convection section caused by soiling in the combustion chamber forces us to clean that chamber while burning. For
this purpose, we use an atomizer with 70 atm compressed air and an air pistol with a 5-mm-diameter nozzle. The results are very good. Care still must be exercised, for a direct blast will remove the protective coating from the tubes.

Shot cleaning was terminated in July 1966 after repeated tube blowouts. Portions of the passes in the plate air preheater were plugged by the shots. The pluggings could not be cleared. Even mechanical means failed. Up to 1 ton of shots were sometimes trapped in the second and third pass.

Cleaning of the air preheater was a problem at plant startup. Shortage in personnel and time did not permit a 100 percent cleaning of the air preheater, even though it was done while the unit was not in operation. With a portable, high-pressure water-booster pump, the same job is done by one man. The water used in this operation is collected and drawn off outside the boiler. To accomplish this, we installed a special conveying system.

The revisions and improvements to the two boilers were completed in the late fall of 1967. The two boilers are now operated at a reduced capacity but with satisfactory availability. Prior to the revisions, the plant availability was 50 to 55 percent. Today, plant availability is 70 to 80 percent (Figs. 22, 23, and 24).
Residue Conveyor

A steel-plate conveyor was selected in the design stage because of the fear that smouldering residue would destroy a rubber belt.

Our operating experience has shown that no smouldering residue is discharged onto the conveyor. However, the residue often contains sharp iron parts (the high portion of industrial and commercial refuse), which certainly would damage a rubber belt.

The wear on the conveyor was so high initially that the expense for repairs after 2500 operating hours was 25 percent of the original price. The speed was reduced by 60 percent through the installation of a gear reducer. The rollers were equipped with oils and were enclosed. These alternations raised the life of the belts to 8000 h. We are presently experimenting with simple plastic bearings, but it is too early in the experiment to discuss the results.

Summary of Combustion Equipment

For a fuel with a calorific value of 2000 kcal/kg, the theoretical combustion air requirement for solid fuel can be computed from the following simplified formula:

\[ L_t = \left( \frac{1.01 \times H_u}{1000} + 0.5 \right) = \left( \frac{1.01 \times 2200}{1000} + 0.5 \right) = 2.72 \text{ Nm}^3/\text{kg} \]

where \( L_t \) is the theoretical combustion air in Nm\(^3/\text{kg}\) and \( H_u \) is the calorific value of a solid fuel in kcal/kg.

However, portions of the refuse have a calorific value of 10,000 kcal/kg, which would require a theoretical combustion air volume of 10.6 Nm\(^3/\text{kg}\). To prevent the formation of gas stratification due to the fuel composition, 390 per cent of excess air would be required. Even this volume of excess air would not solve the problems, since the temperature in the combustion chamber would be so low, if this quantity of combustion air were used, that portions of the gasified refuse would not reach the ignition temperature. Burning with an oxygen deficiency takes place in localized areas on all makes of grates. Whether the air is supplied over the whole grate area at a low volume per unit area or whether it is supplied in zones at a high volume per unit area is not too important for the formation of a reducing atmosphere. Depending on the calorific value of the refuse, strata of unburned gas will form in all combustion chambers.

Another reason for the formation of unburned-gas stratas is the varying thickness of the refuse layer on the grate. Assuming a refuse weight of 250 kg/m\(^3\) and a layer thickness of 1 m, the theoretical volume of combustion air would be 680 Nm\(^3/\text{m}^2\) of grate. An increase of 20 cm in the refuse layer would require an air volume of 816 Nm\(^3/\text{m}^2\).

Higher calorific values and varying layer thicknesses occur, of course, during the combustion process. Excess-air stratas will then form in the valleys with low calorific value.

CONCLUSIONS

Mechanical considerations aside, one must conclude that stratas of unburned gases and of excess air form on all grates. The influence of layer thickness on the formation of unburned gases is extremely strong and sometimes leads to the formation of permanent stratas of unburned gases.

Other factors affecting stratification of the gases are the combustible content of the refuse and the condition of the grate (crack etc.). Proper design of the combustion chamber could prevent a major portion of the fireside damage and would also reduce the soiling of the heating areas. Most of the attention in design should be given to the construction and the configuration of the combustion chamber, because preparing refuse to a uniform fuel would be extremely difficult. The many different characteristics of refuse would first require complete, separate collection or later separation, and it would require separate storage facilities and separate shredding and conveying equipment.
Fig. 23 Operation, Reserve, Repair, and Cleaning of Furnaces, 1967

Fig. 24 Operation, Reserve, Repair, and Cleaning of Furnaces, 1968
Because of the many shutdowns in 1967, unburned refuse (16,000 tons) was stored in a specially prepared area. The stored refuse was burned together with the refuse normally collected in the first 6 months of 1968. Today one can say that the incinerator serves its purpose, the burning of the generated refuse in the City of Mannheim.

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