EXPERIENCES WITH REFUSE INCINERATORS IN EUROPE
PREVENTION OF AIR AND WATER POLLUTION, OPERATION OF REFUSE INCINERATION PLANTS
COMBINED WITH STEAM BOILERS, DESIGN AND PLANNING

H. EBERHARDT and W. MAYER
Kohlenscheidungs-Gesellschaft
Stuttgart, West Germany

ABSTRACT

European steam generators with refuse firing must meet a number of stringent legal requirements for environmental control. Flue dust collectors have over 98 percent efficiency. Difficult physical and chemical problems with the fuel and with boiler availability are met by attention to many engineering details. Corrosion of boiler and superheater tubes is largely prevented by maintaining oxidizing conditions in critical areas.

Leaching tests of raw refuse, composted refuse, and incinerator residue show less ground water contamination from residue.

AIR POLLUTION CONTROL

In Europe, the community authorities are responsible for the elimination and rendering harmless of all domestic and industrial refuse. The communities must make suitable installations available and every property owner is obligated to connect his property to the sewer system and to cooperate with refuse collection according to the community ordinances. According to the effective trade legislation of Germany, refuse incineration plants are subject to approval and must satisfy the Federal Building Code of July 23, 1960. Paragraph 58 of this act specifies that construction projects are permitted only when an acceptable elimination of waste water, natural precipitation and solid wastes is permanently assured. The plants must be designed and operated such that no intolerable nuisances are created. The limit values of permissible nuisances are delineated by the law.

The emission and immission limits (Table 1) can be found in the Technical Specifications for the Prevention of Air Pollution of September 8, 1964. The dust emission of refuse incineration plants with a refuse throughput of more than 20 ton refuse/day may not exceed 150 mg dust/Nm³ clean gas referred to 7 percent CO₂ at any time. Depending on the preload of the site environment, this value must still be lowered so as to remain within the immission limits of 0.42 g/m² day for the annual mean and 0.65 g/m² day for the monthly mean. In industrial centers, the immission values may rise to twice this value. The determining values are
those which are measured in the area influenced by the plant, i.e. in a perimeter of 3 km from the plant site. The legal requirements can only be satisfied with high-grade dust removal systems. As a rule, electrostatic precipitators in a horizontal design with a dust retention of 98 to more than 99 percent are utilized.

With a prescribed clean gas dust concentration, the dust content of the raw gas is of special importance. The cost of electrostatic precipitators (Fig. 1) is influenced by the required degree of dust retention and thus by the raw gas dust concentration.

The amount of dust in the raw gas depends on the particle composition of the refuse, the grate design, the efficiency of the boiler as a fly-ash collector and the method of operating the plant. The component of greatest influence is the ash content of the refuse arriving for incineration and thus the fine-particle fraction of less than 5 mm (0.197 in.). These points become particularly evident in the winter months in areas with a high percentage of coal-fired residential furnaces.

The ash content of residential (Fig. 2) refuse is subject to very extensive seasonal fluctuations. Furnace ash from residential heaters in areas where coal is the predominant home fuel results in more than 60 weight percent ash in the refuse during the winter months. The curves for city areas which are supplied by central heating systems are clearly distinguished from this by their practically constant ash component. The dust content in the raw gas is very substantially influenced by the hearth ash

|TABLE 1| EMISSION AND IMMISSION LIMITS
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Staubemission (Anl. &gt; 20 t Müll/Tag) dust emission (units &gt; 20 t refuse/day)</td>
<td>Jahrsmittelwert annual mean value</td>
<td>Grenzwert limiting value</td>
</tr>
<tr>
<td></td>
<td></td>
<td>150 mg/Nm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.06 grains/cb ft</td>
</tr>
<tr>
<td>Nichttoxische Stäube non-toxic dusts</td>
<td>0.42 g/m²T</td>
<td>0.65 Monatsmittel</td>
</tr>
<tr>
<td></td>
<td>0.6 grains/sq ft day</td>
<td>0.93 monthly mean</td>
</tr>
<tr>
<td>Nitrose Gase nitrose gases</td>
<td>1.0 mg/m³ Luft</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>0.4·10⁻³ grains/cb ft air</td>
<td>0.03</td>
</tr>
<tr>
<td>Chlor chlorine</td>
<td>0.30 mg/m³ Luft</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>0.12·10⁻³ grains/cb ft air</td>
<td>0.009</td>
</tr>
<tr>
<td>Schwefelwasserstoff hydrogen sulphide</td>
<td>0.15 mg/m³ Luft</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>0.06·10⁻³ grains/cb ft air</td>
<td>0.0046</td>
</tr>
<tr>
<td>Schwefeldioxid sulphur dioxide</td>
<td>0.40 mg/m³ Luft</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>0.16·10⁻³ grains/cb ft air</td>
<td>0.011</td>
</tr>
</tbody>
</table>
of domestic heating units. If the fine-particle fraction of less than 5 mm were plotted into the lower diagram, the same characteristic would result as for the total ash content. This also explains the high raw gas dust content of about 15 g/Nm³ (6 grains/cu ft) in the winter months if we only consider residential refuse from municipal areas with individual heating units.

Extreme values are found in those regions where the residential heating demand is mainly covered by brown coal briquettes or where the street cleaning refuse plays a large role. These local characteristics must be taken into consideration during the design work. In these cases, dust concentrations of between 25 and 30 g/Nm³ (10-12 grains/cu ft) can occur in the raw gas.

Normally, refuse is delivered from different city districts and is mixed with trade refuse and sometimes also with industrial refuse, so that the extreme values are equalized. As a rule, dust removal systems are designed for a raw gas dust content of 8-12 g/Nm³ (3.2-4.8 grains/cu ft). The filters are dimensioned such that the gas velocity in the filter amounts to about 1 m/sec for a specified clean gas dust content of 150 mg/Nm³. Depending on the preload of the affected area, a maximum dust concentration of up to 75 mg/Nm³ (0.03 grains/cu ft) is prescribed today by the inspection authorities. In these cases, operation takes place with a gas velocity of about 0.5 m/sec in the filter. Nuisances due to dust emission from incinerating plants are being prevented today by design measures such as installations in the flue gas inlet, and favorable design of the collecting electrodes.

![Graph showing ash content of refuse and dust content of raw flue gas, weight percent](image-url)

**FIG. 2 ASH CONTENT OF REFUSE, AND DUST CONTENT OF RAW FLUE GAS, WEIGHT PERCENT**

**TABLE 2 SO₂ AND HCl EMISSIONS OF REFUSE INCINERATORS**

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>SO₂ (mg/Nm³)</th>
<th>SO₂ (grains/cu ft)</th>
<th>HCl (mg/Nm³)</th>
<th>HCl (grains/cu ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stadt Müllverbr.-Anlagen, ca. 30% Gewerbe-u. Industriemüll</td>
<td>300-400</td>
<td>300-500</td>
<td>300-500</td>
<td></td>
</tr>
<tr>
<td>Municipal incinerator plant, approx. 30% industrial waste</td>
<td></td>
<td></td>
<td></td>
<td>0.122-0.163</td>
</tr>
<tr>
<td>Industriemüll-Verbr.-Anlagen, &gt;50% chem. Abfälle</td>
<td>300-700</td>
<td>1100-2900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incinerator for industrial refuse, &gt;50% chem. waste</td>
<td>0.122-0.286</td>
<td>0.448-1.182</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ölbefeuerte Dampfkessel, oilfired boilers</td>
<td>2000-2500</td>
<td>0.815-1.020</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

75
Today, retentions of more than 99.5 percent can be attained with E-filters. In older plants in which the separation of carbonized paper particles could not be solved satisfactorily, an electrostatic spring-steel precipitator has successfully been series-connected with the E-filter.

The emission values for gaseous materials depend practically exclusively upon the refuse composition, the proportion of plastics and industrial refuse in municipal incinerators. In such plants it has been found that the SO₂-content amounts to about 0.03 vol. percent and that the maximum HCl content ranges around 0.02 vol. percent in the wet flue gases. In industrial refuse incineration plants with a high percentage of chemical wastes, an SO₂-content of 0.11 percent and an HCl concentration of up to 0.25 percent must be expected. The more than ten-fold increase of the HCl emission is explained by the fact that a large part of plastics is based on polyvinyl chloride.

In the case of the gaseous emissions of refuse incinerators, (Table 2) only the sulfur and the chlorine content

### TABLE 3

<table>
<thead>
<tr>
<th>Extraktion</th>
<th>Nr. 1</th>
<th>Nr. 5</th>
<th>Nr. 10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>K</td>
<td>S</td>
</tr>
<tr>
<td>Phenolphtal.-ALK. p-Wert</td>
<td>2.3</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>phenolphtal. alkalinity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methylorange-ALK. m-Wert</td>
<td>8.0</td>
<td>2.5</td>
<td>0.7</td>
</tr>
<tr>
<td>methyloange alkalinity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH – Wert</td>
<td>8.8</td>
<td>6.6</td>
<td>8.0</td>
</tr>
<tr>
<td>Gesamthärte</td>
<td>9.3</td>
<td>72</td>
<td>2.2</td>
</tr>
<tr>
<td>total hardness °dH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kaliumperm. – Verbr.</td>
<td>26</td>
<td>1620</td>
<td>3.0</td>
</tr>
<tr>
<td>KMnO₄ – consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdampfrückstand</td>
<td>360</td>
<td>2682</td>
<td>76</td>
</tr>
<tr>
<td>exhaust — steam residue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glührückstand</td>
<td>101</td>
<td>1893</td>
<td>66</td>
</tr>
<tr>
<td>annealing residue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>73</td>
<td>564</td>
<td>19</td>
</tr>
<tr>
<td>MgO</td>
<td>14</td>
<td>112</td>
<td>2.0</td>
</tr>
<tr>
<td>Fe</td>
<td>0.1</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Mn, Cu, Cr, Pb, Ni</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Al</td>
<td>1.0</td>
<td>0</td>
<td>0.4</td>
</tr>
<tr>
<td>Ba</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SiO₂</td>
<td>2.5</td>
<td>12.5</td>
<td>2.5</td>
</tr>
<tr>
<td>NO₃</td>
<td>&lt;1</td>
<td>280</td>
<td>&lt;1</td>
</tr>
<tr>
<td>NH₃</td>
<td>0.1</td>
<td>1.0</td>
<td>0</td>
</tr>
<tr>
<td>SO₄</td>
<td>22</td>
<td>1136</td>
<td>0</td>
</tr>
<tr>
<td>Cl</td>
<td>3.0</td>
<td>200</td>
<td>2.0</td>
</tr>
</tbody>
</table>
must normally be considered. No nitrous gases could be detected in the flue gases even in a plant in which refuse was incinerated. Free chlorine could not be found in the flue gases even with an extremely high chlorine percentage in the refuse; it is always present in the form of hydrogen chloride. It is of interest that although the SO2 concentration amounts only to 1/10 of the value in oil-fired steam boilers, the SO3 content is higher than in oil-fired systems.

In the case of refuse incineration, 15-20 percent of the sulfur oxides are present as SO3, while the SO3-fraction amounts only to 1-2 percent in oil furnaces. The sulfur content of heavy fuel oil amounts to between 0.5 and 1 percent, while it is 0.3 percent in refuse. The higher concentration of sulfur oxides in oil-fired boilers can be explained by the low excess of air and the smaller volume of flue gas compared to refuse boilers in which the process takes place with the ten-fold volume of flue gas.

**WATER POLLUTION CONTROL**

According to the Act of Water Conservation of July 27, 1957, refuse can only be disposed of such that a harmful pollution of ground and surface water or any other unfavorable change of its properties are prevented. Limiting values are not specifically defined, except that the degradable substance of the slag (residue) is limited to 0.3 percent.

In some cases, opinions have varied concerning the influence of the disposal of incinerator residue on ground water as compared to composted refuse. The predominant opinion was that the disposal of composted refuse is acceptable for ground water in contrast to incinerator residue. This concept is correct only when the compost is distributed in a thin layer over agricultural land and all leaching is immediately absorbed by the vegetation. Banking of composted refuse in the case that it cannot be sold or disposed of completely would represent a serious danger for ground water. The influences of compost as well as of residue on ground water have been determined in experiments; an extraction of the samples furnished the data in Table 3.

The salts in the wastes are not chemically bound to organic compounds. They are either absorbed or occluded and can be leached by water. In the tests, the slag was finely ground and the surface-to-volume ratio was thus changed unfavorably. The extraction was carried out with distilled and carbon dioxide-saturated water and 10 eluates were analyzed in each case. The results are precisely comparable, although we can expect a smaller amount of leaching in reality in view of the more unfavorable experimental conditions compared to natural conditions. The results show that attention should primarily be paid to the nitrate (NO3), but also to the sulfate (SO4); two orders of magnitude more of both are leached from refuse compost than from slag. In the case of ground water with an inherently high chloride content, the elution of chlorides, which are higher by two orders of magnitude in compost, is much more likely to have a disturbing influence. Furthermore, we must note the higher ammonium leaching from the compost and leaching of hardeners (CaO and MgO) which are also considerably higher than in residue. The eluates of refuse slag are alkaline in contrast to those of compost, which are acid, and consequently tend less toward reactions with soil components.

The far more favorable characteristics of incinerator residue compared to compost in the connection discussed above are a consequence of the high temperature to which the salts are exposed during combustion in the presence of oxygen. When organic compounds with their salts are exposed to the effect of heat, however, a chemical conversion takes place with most salts. In the case of bed temperatures of more than 800 °C (1472 °F), which are customary in refuse fire chambers, the salts are partly converted into the oxides which are slightly soluble or insoluble in water; in part, they form glassy water-insoluble substances with silica (SiO2).

**FURNACE AND BOILER DESIGN**

Government grants for electric power companies for financing and depreciation of steam generators which were equipped with main or auxiliary firing systems for refuse were the instigation for the construction of plants with steam outputs and parameters as those customarily found in highly efficient turbine operations. An additional reason for the combination of refuse incineration with a steam boiler is the need for high-grade dust precipitation systems which, however, can only be subjected to a maximum of 250-300 °C (482-572 °F). The most economical solution for cooling of flue gases with a temperature of 800-1100 °C (1472-2012 °F) for medium-sized and larger refuse incinerator units (> 5 t/h refuse incineration capacity) consists of a series-connected steam generator.

After a few years of operation of large plants, it can be concluded that boilers with refuse fire chambers including the accessory equipment differ fundamentally from conventional plants in design and operation. It therefore seems appropriate to consider them in detail.
in their design and characteristics compared to plants operating with fossil fuels.

The core of every refuse incineration is the firing chamber. The refuse incineration must be adapted to a wide range of varying refuse properties, in contrast to conventional furnaces which are operated with one or several strictly specified fuels. In Central Europe a lower heating value of 800-2500 kcal/kg is demanded for refuse by the consumer. Variations in moisture content of up to a maximum of 50 percent and in the ash content of up to a maximum of 60 percent and in the combustibles of at least 25 percent, for example, are agreed upon for the incineration of refuse without auxiliary heating. In the same manner, the supplier cites a lower limit for the heating value of between 1000 and 1200 kcal/kg up to which the refuse can be incinerated without the support of external heat.

Each fire chamber has a maximum and minimum incineration capacity in tons refuse/hr depending on its grate area. The limiting output depends on the combustible material in the refuse, on whether the latter consists primarily of cellulose or mainly of carbon. In addition, the incineration capacity is limited by the upper and lower refuse heat output in kcal/hr which results from the thermal load on the grate area in kcal/m²h.

On the boiler side, the limits for the heat supply from refuse incineration are established by the maximum permissible superheater and waste gas temperature on which the heat engineering calculations and the choice of materials are based.

The relation between the different limiting values is most clearly apparent from the so-called refuse incineration diagram (Fig. 3). The refuse throughput is plotted on the abscissa and the heat output on the ordinate; the lower heating values are represented by a family of straight lines.

Two lines parallel to the ordinate define the maximum and minimum refuse throughput on the basis of established refuse characteristics. Two straight lines parallel to the abscissa define the maximum and minimum heat output of the basic fire chamber. The rectangle ABCD is thus generated in which the lower right corner is cut off by line GH according to the refuse

---

**FIG. 3 REFUSE INCINERATION DIAGRAM**

78
with the lowest heating value which can be incinerated without heating assistance, while the upper left corner is cut off by the line EF of the maximum heating value for which the fire chamber has been designed.

Experiences of recent years show that the annual increase of the refuse heating value is higher than had generally been assumed during planning work. The installed combustion chamber and boiler size, and thus, the fixed maximum thermal output, then force the operator to reduce the refuse throughput when the upper heating value is exceeded.

The difficulties in the planning and design of incineration plants usually result from the trade and industrial waste component. While the analysis of residential refuse is a relatively simple procedure, the determination of the volume and composition of industrial refuse is especially difficult. The data reported by industry are monthly or annual mean values, but the predominant volume actually is often produced in a few days of the year. This results in an enormous load on the refuse incinerator.

As a result of the increase in the volume of refuse but primarily because of an increased heating value, the limiting values were raised for the expansion of the described systems. This means, however, that the field below AGH (Fig. 3) for which heating support is necessary becomes larger. To obtain the most economically operating plant for the given local conditions, it is necessary to determine the size of the fire chamber by an economy calculation. The diagram shows that the desire for incinerating the maximum volume of refuse even at a maximum heating value is not economically justified.

**BOILER FOULING AND FIRESIDE TUBE WASTAGE**

The pressure section of the boiler is constructed for a fuel with a very high ash content and must be provided with sufficient cleaning equipment. The operator of a steam boiler which is combined with refuse incineration must deal with special conditions with regard to operating time and corrosion on the pressure section. These operational problems — such as short operating time with values of 1½ and 3 months and corrosion on certain heating surfaces — can be reduced to a certain degree by a suitable preparation of the refuse to operate as fuel. In the case of wide fluctuations in the composition of the delivered refuse, good mixing is a prerequisite. Special requirements of a delivery appropriate for firing must be stipulated for industrial refuse. Complete combustion can take place only by a homogeneous charge and a homogeneous fuel bed with a correct distribution of the combustion air. This, however, is a prerequisite in order to maintain fouling and corrosion of the heating surfaces in tolerable limits. The corrosion rate is partly a function of fouling, so that its reduction goes hand in hand with an increase of the boiler life as well as with an extension of the operating time.

Fouling on the flue-gas side shown in Fig. 4 is the main problem of most large-scale plants. After 1200-2000 h of operation, the installations must be shut down since extensive fouling of heating surfaces has increased the loss of draft by 60-100 mm (2.4-3.9 in.) H₂O and the exhaust gas temperature by 60-80 °C. Fouling depends on the flyash content and its composition as well as on the configuration of tube panels which have a staggered arrangement in the present case. Slag formation on horizontal tube coils is considerably greater than on suspended heating surfaces, which can also be cleaned more easily.

![Fig. 4 Fouling of a Superheater Heating Surface](image-url)
A cross-section through the deposit on the leading-side of a final superheater tube shows the following from the tube wall to the outside:

a) A thin wustite (FeO) layer.

b) Inside this, a porous and cracked layer permeated by whitish streaks consisting of the decomposition products of complex sulfates with a high hematite concentration.

c) This third layer makes a transition into a sintered zone permeated by whitish streaks containing primarily sulfates and ash.

d) A heavy, more or less agglomerated layer of fly-ash.

e) Alkali silicates can be recognized in this layer in the form of rounded fusion beads.

The slag consists in part of low-melting eutectics, the formation of which can be explained by the refuse composition. Consequently, the deposits remain pasty and tacky down to temperatures of 550°C (1022°F) and thus adhere up to the area of the presuperheater, where the medium temperature is 400°C (752°F) and the flue gas temperature ranges between 500 and 600°C (932-1112°F).

In the analysis of the deposits, a distinct odor of H₂S is regularly detected which can only form with an air deficiency. However, today all incinerators are operated with an excess of air of 70-80 percent and more, and reduction processes must therefore take place within the slag deposits. A local ignition caused by glowing fly-ash constituents can actually be observed on fouling deposits of superheater tubes; this explains the formation of sulfides. The layer of scale between tube wall and deposit (indicated by a and b in Fig. 8) has a thickness of 0.05-0.15 mm (0.002-0.006 in.) after a few hundred hours of operation in the present case, but may amount to 1-3 mm (0.04-0.12 in.) after a few thousand hours of operation. Scale-like erosions on the tubes of the final superheater—primarily at the first leading row of tubes—are the first corrosion phenomena in nearly all refuse incineration plants. In the course of further operation, erosions are also observed on other heating surfaces. After the first thousand hours of operation, it was found that up to 25 percent of the wall thickness had eroded on final superheater tubes.

In regular controls of the wall thickness, it was found unexpectedly that the material wear approaches a limiting value allowing us to anticipate an acceptable tube life. The reason for this is a certain corrosion protection by the slag formation on the heating surfaces. During cleaning of the tubes, care must therefore be taken that a hard shell of 3-5 mm (0.12-0.20 in.) is left as the so-called basic fouling. The corrosion rate increases linearly up to about 1000 h of operation (Fig. 6) and then flattens gradually, approaching a limiting value asymptotically. A listing of absolute values was omitted because these differ for every plant and depend on the refuse composition, the operating procedure, and the dilution of the refuse flue gases, i.e. whether the refuse incineration
participates in the boiler output as the main firing contribu-
tion or only by a small percentage.

In the incineration of refuse with a large percentage of
coal ash during the winter months, it was found that the
corrosion rate decreases in comparison to summer opera-
tion. The ash from coal furnaces acts as an inhibitor;
this was confirmed in combination plants in which pow-
dered coal firing represents the main fuel through which
the refuse flue gases must necessarily flow.

The erosion of tubes at certain points in the fire
chamber has a similar appearance to that on the final
superheater, i.e. layers of scale, which easily flake off,
are located under the shell-like deposits. However, while
the process slows down at the superheaters, the cor-
rosion rate on the heating surfaces of the fire chamber
continues approximately linearly. The reason for this
resides in the flue gas composition—in the influence of
secondary air. Channeling of the atmosphere with zones
of air deficiency, and thus reduction processes in the
combustion chamber, cannot be avoided. To this we
must add the influence of the flame front which still
contains a large quantity of glowing and thus incom-
pletely burnt parts that continuously subject the iron
oxide layers to renewed reduction on contact.

It is apparent from these considerations that high-
temperature corrosion is involved in all cases. Several
theories exist concerning the chemical process of cor-
rosion which have been discussed in detail in the studies
of Dr. R. Huch, Dipl.-Chem. Fr. J. Angenend and Dr. H.
Köhle. The refuse or the fouling deposits, respectively,
contain practically all elements of the periodic system.
Consequently, the most diverse corrosion processes can
take place among which the formation of complex
alkali sulfates and of chlorides together with reduction
processes probably constitute the major contribution.

The developments in the chemical industry in the
field of synthetics are of particular interest in this con-
nection. The unusually widespread plastics based on
polyvinyl chloride today contain 80 percent chlorine
instead of the previous 57 percent in order to improve
the heat stability of the material.

Even if it should be possible to find a complete inter-
pretation of the chemical mechanism of corrosion, it will
hardly be possible to derive suitable countermeasures
from this aspect. After experiences were available, pos-
sibilities were sought and found for the control of the
fouling and corrosion problem in refuse incineration
plants.

Mannheim is an industrial town in southern Germany
with a population of about 350,000. The municipal
refuse incineration plant (Fig. 7) also incinerates fairly
large quantities of industrial wastes which differ highly
from domestic and ordinary trade refuse in heating
value, combustion behavior and chemical composition.

Just a few years ago, the main problem in planning and
design was the incineration of refuse with a low heating
value (less than 1000 kcal/kg), so that larger quantities of
oil had to be burnt at the same time as ignition and sup-
porting fuel. As a result of the actual considerably higher
volume of refuse from the chemical and lumber-process-
ing industry, the refuse heating value periodically rose well
above the upper limit (2200 kcal/kg) on which the design
was based. Thermal overloads occurred with consequent
damage of the fire chamber and the boiler heating
surfaces.

Such difficulties can be overcome only by the coopera-
tive efforts of the operator and the supplier. The suppliers
must observe certain specifications for problematic wastes
(plastics, rubber, carbon residues from oil, colorant
residues, greases, etc.), such as maximum sizes of pieces
and bundles, and limits on the maximum daily deliveries.
This is a prerequisite in order to permit sufficient mixing
with the other refuse with a limited bunker surface area. Firing had to be adapted to requirements (higher excess of air, high-quality coating for grates). It is a more difficult problem to adapt an existing boiler to experiences concerning the fouling characteristics of refuse dust and the corrosion mechanism, which extensively depend on the refuse composition. Naturally it was possible to rebuild the heating surfaces, which in part were in offset arrangement, into an aligned form in the third flue; but a reduced performance compared to the theoretical values had to be accepted because of the diminished heat transfer as a result of fouling and cladding of the heating surfaces.

The possibilities on the side of the fire chamber have already been described—i.e., good mixing of the refuse before loading into the combustion zone, metering of the fuel and of the combustion air, a tailored supply of secondary air, and a suitably designed fire bridge. We believed it possible to prevent fouling and corrosion on the boiler side by additives. The slag deposits admittedly became looser and could be removed more easily, but a decrease of corrosion could not be achieved. The expenses involved in neutralizing the considerable quantities of fly-ash are not justified. Attempts to use a sandwich cladding of the tubes with chrome and aluminum oxide did not produce a satisfactory result since the surface of the protective layer could not be formed without pores. Good results were obtained with tube shells which were welded as half- or full-shells on the first and partly also on the second row of tubes of the leading superheater bundles and which consisted of metallic and ceramic materials, respectively.

The fouling deposits no longer make contact with the superheater material, so that a sufficient corrosion protection is afforded. A corrosion purely due to gas has not yet been detected.

An effective measure in the fire chamber has proved to be the installation of studs and cladding of the tubes in the flame zone with a ceramic tamping material.

This method was used for the first time in the refuse power plant of North Munich (Fig. 8). After an operation of 1 1/2 years it was found that no corrosion takes place under the protective coating in contrast to earlier conditions when the tubes in this zone had to be replaced after a few thousand operating hours. The ceramic coating of about 10 mm (0.39 in.) thickness is not impervious to gas, but it is sufficient to prevent contact of the tubes by slag deposits.

The neutralizing action of ash from coal furnaces was taken into account in the further expansion of the Munich refuse incineration. Powdered coal firing (for (80-100 percent of the boiler output) was arranged over the refuse firing (for 20 percent of the boiler output) in the same boiler flue. It is a disadvantage that the refuse grate must also be in operation when no refuse is incinerated and only coal is burnt, and in addition, the large volume of ash from a powdered coal firing for a 360-ton (790,000 lb/hr) steam boiler must be transported through the refuse fire chamber.

Fig. 9 shows a new high-output boiler for 365 t/h steam at 186 atm and 540°C with refuse support firing for about 20 percent of the steam output. Past experiences were taken into consideration in the design:

1) Fire chamber side: Adjustable bed height over the charging grate, resulting in improved metering corresponding to the refuse constitution. Increase of the flow resistance in the grate bed unifying air distribution over the undergrate zones independent of the fuel bed. Arrangement of a fire bridge for which an oil ignition burner creating effective secondary air supply for homogenizing the flue gas atmosphere and for complete fly-ash combustion. Air excess of 80 percent fluctuating between 60 and 100 percent.
DAMPFLEISTUNG
STEAM OUTPUT
HD - TEMP
SUPERHEATER TEMP
HD - DRUCK
SUPERHEATER PRESS.
ZÜ - TEMP
REHEATER TEMP
ZÜ - DRUCK
REHEATER PRESS.

365 t/h
800,000 lb/hr
540 C
1004 F
186 atü
2650 p.s.i.
540 C
1004 F
44 atü
62.5 p.s.i.

FIG. 9 FORCED CIRCULATION BOILER WITH REFUSE SUPPORT FIRING
2) **Boiler side:** Ceramic combustion chamber in the entire flame zone; only a so-called grate cooling band to prevent caking and damage on the chamber wall in this zone. Radiant heating surfaces as smooth side walls consisting of evaporator tubes.

No superheaters in the flue gas flow of the refuse section; only a part of the economizer to lower the gas discharge temperature in the form of an aligned contact heating surface. Mixing of the refuse flue gases with the total flue gas stream before the air preheater.

In the design and construction of the boiler, consideration was given to the experiences of recent years in the incineration of refuse in high-output boilers. The calculated heating surfaces in the refuse section were overdimensioned by 30 percent on the basis of data concerning the fouling properties of flue dust. This installation is designed for residential and trade refuse with a small proportion of industrial refuse which amounts to about 10 percent in municipal incineration. Fig. 10, in contrast, shows an installation especially for industrial refuse.

The plant is designed for 7.5 t/h solid refuse with a lower heating value of 4400 kcal/kg and for 1.8 t/h liquid wastes. The liquids with a heating value of about 10,000 kcal/kg are sprayed and burnt in special burners over the traveling-grate fire chambers; sufficient experiences are available on this subject. Compared to the plant which was described previously, two turn-overs are sufficient for this refuse with its low inert content, i.e. one charging grate and only two incineration grates.

The steam output of the boiler amounts to 71 t/h (156,000 lb/hr), the superheated steam temperature is 280 °C (536 F) and the rated pressure is 25 atm (367 psi). In the horizontal flue, all heating surfaces (a superheater bundle, five evaporator and two economizer bundles) are in aligned and suspended arrangement, and can be easily dismantled from the top. Cleaning of heating surfaces is done by means of soot blowers and shaking devices. The tube wall thicknesses were overdimensioned to allow for the high corrosion rate during the first 2000 h of operation.

**FIG. 10 INCINERATOR PLANT FOR INDUSTRIAL REFUSE**
The above considerations indicate that large refuse incineration plants today are fulfilling their main task of converting refuse into sterile end products, and in addition, the generated heat can be utilized for power production through high-performance boilers. The present availability of such plants amounts to between 50 and 80 percent. It is believed that operating periods of more than 4000 hr will be possible with planned new boilers. Naturally, it is simpler and less difficult to combine refuse incineration with a saturated-steam or hot-water boiler; however, in Europe only very limited possibilities exist to guarantee a summer consumption of the generated low-pressure steam and hot water.

**SPECIAL RECOMMENDATIONS**

In order to complete our considerations, we must also briefly touch on the subjects of an operationally reliable refuse incineration with its crucial accessory equipment and the refuse bunker as well as the management of refuse delivery; some of these experiences have been described in another connection.

The refuse bunker has frequently turned out to be the bottleneck in the operation of the plants. The refuse is often more voluminous than anticipated; residential refuse varies between 200 to 300 kg/m³ (336-503 lb/cu yd), and trade and industrial refuse has bulk density of about 150 kg/m³ (251 lb/cu yd), so that the bunker capacity is frequently insufficient. The floor area of the bunker is particularly important, while a suitable width is indispensable to permit tipping of the refuse trucks and stacking of the stored refuse.

With a sufficient floor area and a limited bucket volume (maximum of about 4 m³ or 5 cu yd), good mixing of the delivered refuse can be achieved.

A good solution for a refuse bunker is shown by the Dusseldorf design (Fig. 11). The trucks dump into a hole and the refuse is pushed into the bunker space proper by means of a scraper. The refuse is picked up by the bucket and dumped over the stacking area, so that mixing necessarily results.

Bulky refuse (old household equipment, such as furniture, etc.) and large wastes from trade and industry must be size-reduced. Impact mills as well as shears have proved useful for size reduction.

Crane systems in Europe are usually equipped with orange-peel buckets. The equipment must be installed in duplicate and it should be possible to move the crane from the working area for repairs. Cable wear is high in these installations but some improvements have been made with a more favorable cable traveling guide. Weighing and recording of each bucket load before dumping into the charging chute of the fire chamber, together with the indications of the boiler output, result in a good control of the load on the plant.

Sorting of certain refuse components, such as smaller iron pieces, tin cans, fine ash, etc., is generally not done. It is necessary, however, to set certain requirements for the refuse suppliers and to inspect the trucks from this aspect. To prevent mechanical problems, larger incombustible goods, such as steel beams, automobile shafts and springs, furnaces and stoves, etc., may not be included and bulky combustibles, such as davenports, wardrobes, railroad ties, tree trunks, etc., must be reduced prior to incineration. Thermal overloads and damage on the fire chamber and boiler occur when thermoplastic and liquid materials of high heating value are delivered in larger quantities, big pieces or bulky bundles. Several cities treat problematic industrial refuse in incineration plants that operate without waste heat boilers, and in some cases with flue-gas scrubbers or catalytic flue-gas scrubbing. In some refuse plants, incineration is followed by residue treatment.

Under certain conditions, the investment for a separation of scrap iron from the residue and separate scrap sales are economically justifiable. One large-scale plant carries out subsequent residue sintering.

In conclusion, we emphatically stress once more the special requirements for refuse incineration plants with their differences and special problems compared to conventional steam boilers and their accessory equipment. The differences apply not only to the boiler but also to the fuel delivery, its storage and preparation as well as to the removal of dust and processing of residue. The main task of a refuse incineration plant, i.e., the con-
version of wastes into sterile end products, must always remain the primary factor in all considerations.

REFERENCES


