European Practice in Refuse Burning

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Abstract

The practice and type of design in some of the European municipal incinerators are described. Special attention is given to design of grates. Data is given on amount of refuse per capita, analysis of refuse, heat recovery, and some of the details of European design.

Introduction

The rapid expansion of present day urban and suburban developments and generally improved standards of living produce as an undesirable side effect a huge increase in refuse from homes as well as industry. The problem of disposal of the collected material in a sanitary manner without contaminating the atmosphere or the ground water has plagued the large European cities for a long time. The recent developments and performance of some large municipal refuse incinerators are compared in this paper.

The staggering problem of refuse destruction by incineration in our large cities has been recognized by municipal authorities as one which requires immediate attention for a satisfactory solution. Many sincere as well as makeshift attempts have been made in a totally unorganized effort to solve this problem.

The ASME Incinerator Committee is charged with the coordination and organization of efforts to develop recommendations for the most satisfactory incinerator construction.

It is the object of this paper to describe the present day practices at some of the major European municipal incinerator installations which were observed during the summer of 1963 for the express purpose of assisting the ASME Committee in arriving at some preliminary conclusions for establishment of design criteria.

The incinerators inspected are each of a basically different design and represent a partial picture of the incinerator evolution from the early batch type furnace to the large municipal power plant complete with steam generators, dust collectors and electrostatic precipitators. Special attention has been paid to the method of refuse burning on the grates and the flow of the products of combustion through the furnace.

Table I shows the installations visited and types of incinerator grates used. Information was also made available on the Karnap design and the Esslingen design, but performance observation and operational data were not obtained due to lack of time.

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of Units</th>
<th>Total Capacity</th>
<th>Type of Grate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris</td>
<td>4 @ 9.4 ton/hr</td>
<td>37.6 ton/hr</td>
<td>Volund</td>
</tr>
<tr>
<td>Munich (Mortin)</td>
<td>2 @ 28.0 ton/hr</td>
<td>56.0 ton/hr</td>
<td>Mortin</td>
</tr>
<tr>
<td>Duesseldorf</td>
<td>1 @ 11.0 ton/hr</td>
<td>11.0 ton/hr</td>
<td>Dueseldorf</td>
</tr>
<tr>
<td>Hamburg</td>
<td>5 @ 11.0 ton/hr</td>
<td>55.0 ton/hr</td>
<td>von Roll</td>
</tr>
<tr>
<td>Munich (Semler)</td>
<td>1 @ 0.25 ton/hr</td>
<td>0.25 ton/hr</td>
<td>Semler</td>
</tr>
</tbody>
</table>
It is not possible to make a totally fair evaluation of the performance of these installations as some were operating with partial to full load while others were strain¬ing under considerable overloads. Such overloads tend to distort the operational observations with unfavorable maintenance, wear and dust loading reports.

Plant housekeeping and maintenance at each installation was very good. It is felt that this contributed considerably to the excellence of performance. Automatic controls were applied as far as possible and manual stoking, cleaning and ash removal were reduced to a minimum.

The inspections made at the various municipal plants were extremely informative thanks to the courteous and splendid cooperation of the managers and directors at each plant. The information made available during these visits and the observations made are summarized below.

**The Volund Incinerator at St. Ouen (Paris)**

The Volund Incinerator, which was originated in Denmark is presently widely used with about 30 units of this type in successful operation (see Figs. 1-3).

The Volund incinerator consists of two inclined reciprocating grates, the drying and the ignition grate, and a final burning stage in a slightly inclined rotary kiln.

The diameter of the rotary kiln limits the grate and furnace width. The rotary kiln at St. Ouen is about 9 ft in diameter which is fed from a grate 8 ft wide.

The gases can travel over one of two separate paths from the combustion area over the grates to the open flue upstream from the waste heat boiler where they mix with forced draft air for completion of combustion. One portion of the gases travels backward in the direction of the drying grate section and then forward to the open flue through the by-pass duct. This flow can be controlled by means of a refractory lined gate in the by-pass duct. The other portion of the gases travels through the rotary kiln and discharges into the open flue.

The ashes and clinkers are dropped off the lower end of the rotary kiln into a water filled channel which is flushed out periodically with an impact flow of four cubic yards of water. It is claimed that this method is very successful. Drag chains and other ash conveyor means requiring constant maintenance and repair are not used. No water cooling is utilized in the furnace section above the grates.

**The Martin Incinerator at Munich**

The design of the Martin grate has been used for many years for the successful combustion of lignites and brown coals with high moisture content. Several incinerator installations of this type are in successful operation both in Europe and South America.
The Martin incinerator at Munich (Fig. 4) consists of a 3 section wide reverse acting grate inclined to an angle of about 35 degrees. The upward or reverse motion of this grate (Fig. 5) causes a gentle tumbling action as the refuse flows down the grate slope. The hot gas flows counter to the direction of the refuse flow whereby the drying action is fully utilized. After completion of combustion the ashes are discharged from the grate over a rotating ash and clinker dam, through a clinker crusher and into a water filled ash trough from which they are periodically dumped onto an ash conveyor. The furnace above the combustion zone is fully water cooled.

The "Duesseldorf" Incinerator at Duesseldorf (Fig. 6)

The so-called "Duesseldorf" system of incineration was developed by the Engineering Department of the City of Duesseldorf and consists of an inclined row of rotating grate cylinders. It is the first installation of this type. The results are reported to be very satisfactory (Figs. 6, 8, 9).

**Fig. 4. THE MARTIN INCINERATOR (MUNICH).**

a) Refuse hopper  
b) Reverse acting grate drive  
c) Reverse acting grate  
d) Water cooled furnace section  
e) Ash and clinker discharge  
g) Clinker chill  
h) Ash conveyor

**Fig. 5. DETAIL OF THE MARTIN REVERSE ACTION GRATE.**

**Fig. 6. THE DUESSELDORF INCINERATOR AT FLINGERN.**

a) Refuse hopper  
b) Refuse feed gate  
c) Feed gate drive  
d) Rotating grate drums  
e) Travelling grate  
f) Steam generator  
g) Oil burner  
h) Ash and clinker discharge

**Fig. 7. THE DUESSELDORF INCINERATOR, AT STUTTGART.**

a) Refuse hopper  
b) Refuse feed gate  
c) Rotating grate drum  
d) Water cooled furnace section  
e) Ash and clinker discharge  
g) Clinker chill  
h) Ash conveyor
The unique rotating cylinder action transports the refuse from cylinder to cylinder in a gentle agitation for thorough combustion. Each cylinder has its own variable speed drive to suit the refuse feed and combustion rate. The speed can be varied from one to 4 revolutions per hour. The cylinders are used in widths of 10 or 20 ft.

The original installation was constructed with four rotary drums and a final travelling grate section. The travelling grate has proven to be unnecessary as combustion is completed in the rotary drum section of the grates. All new installations will have 6 or 7 rotary drums only (Figs. 7, 14).

The wear, repair and maintenance on this grate is reported to be remarkably low with 13,000 hours of operation without grate repair or replacement. The clinkers are presently dropped into a clinker chill bath from which they are removed by a conveyor to the ash storage. Water cooled walls are presently not used, but new projects will be fully water cooled above the primary combustion zone similar to the layouts shown in Figs. 4 and 15 for the “Martin” system.

The Rotating Grate Action - Side View

The wear, repair and maintenance on this grate is reported to be remarkably low with 13,000 hours of operation without grate repair or replacement. The clinkers are presently dropped into a clinker chill bath from which they are removed by a conveyor to the ash storage. Water cooled walls are presently not used, but new projects will be fully water cooled above the primary combustion zone similar to the layouts shown in Figs. 4 and 15 for the “Martin” system.

The Rotating Grate Action - Cross Section

The von Roll Incinerator at Hamburg

The City of Hamburg has been active in the field of refuse incineration since 1896. The experience over the years with various types of incinerators has resulted in the selection of the von Roll system designed in Switzerland (Fig. 10).

In principle the system is similar to the Volund system (see Fig. 1) except that a vertical slag generator, with an annular ring for admission of an air and steam mixture for final combustion is used in place of the inclined rotary kiln. Also the two-way gas passages are eliminated. Instead the gases flow straight upward in the direction of the flue to the steam generator.

The grate width of 5 ft, 7 in is limited by the diameter of the slag generator, roughly 6 ft as it is in the case of the Volund system (Figs. 2, 3). The ashes and clinkers accumulated in the slag generator are discharged periodically into the quench bath. A drag chain transports the residue up to a conveyor for final disposal. Water cooling is not utilized on the furnace walls of the primary combustion chamber.

The Karnap Installation in Duesseldorf

The experimental installation at Karnap consists of a furnace with 3 travelling grate stokers, arranged at three different levels (Fig. 11). Besides the tumbling results from dropping the refuse from each travelling grate, additional agitators create supplementary refuse tumbling to accelerate the completion of the combustion process. The gas flow in the furnace is parallel to the refuse flow towards the steam generator.

An auxiliary pulverized coal burner is installed at the rear end of the furnace directed toward the grate to complete the refuse combustion and also to balance the load in the steam generator. The clinkers and ashes are off the last travelling grate stoker into a quench trough. They are removed from the trough by means of a conveyor to the storage area. The grate width is not limited and standard chain grate stokers can be used in this furnace.
The furnace section above the last grate is fully water cooled.

The Esslingen Incinerator at Stuttgart – Mohringen

Another method of refuse conveying and agitation on the grates is shown in Figs. 12 and 13. These grates are of the rocker type. Each grate bar is tilted individually and in a coordinated sequence with the adjacent bars to create a continuous downward wave motion over the entire grate incline. This action, in addition to moving the burning refuse at the desired burning rate, causes sufficient agitation of the refuse for proper drying, aeration, and thorough combustion. Additional secondary air is admitted under the furnace arch for complete burn-out of all volatile gases.

Carry-over of fly-ash into the atmosphere is greatly reduced as the refuse is not tumbled or dropped from one grate section to another. Waste heat boilers with dust collectors and electrostatic precipitators may be applied. Ash and clinkers are dropped in the usual manner from the end of the grate. The grate width is limited for structural reasons. The furnace above the combustion zone may be fully water cooled.

The New Refuse Incinerator Plant at Stuttgart

The new plant under construction at the City of Stuttgart shows a definite trend in the latest thinking of incinerator application (Figs. 14 and 15). The selection of the “Martin” incinerator grate in combination with the pulverized coal fired steam generating unit resulted from performance studies of many different incineration methods.
The general steam generator arrangement follows the layout for the City of Munich, with a “Martin” incinerator (Fig. 4) in connection with an oil-fired steam generator. The second unit is built identical to the first except that a Dusseldorf type incinerator (Fig. 7) will be installed. It is interesting to note that a true performance evaluation of the two types of incinerator grates will be made and that the projected third unit will be furnished with the best performing grate. Both incinerator types will be interchangeable for replacement by the better grate in case of unsatisfactory performance of the other. The performance results will be obtained during the year 1964 and should prove, not alone very valuable, but they will also indicate a definite direction for future incinerator design.

The Semler Incinerator (Fig. 16)

All incinerators shown so far have been in the capacity range between 5.0 and 30.0 tons of refuse per hour. In nearly all cases the installation of waste heat boilers was not only justified, but was necessary to reduce the gas temperature for proper fly-ash removal in dust collectors and electrostatic precipitators. For smaller municipalities, villages, institutions and resorts where continuous firing is not warranted the Semler incinerator with a capacity range from 1100 to 3200 lb/hr may be a good answer.

In this design (Fig. 16), the basic incinerator grate is a rotating inclined cone. The saucer shaped cone is perforated for combustion air admission and the rotational motion results in a tumbling of the refuse for good primary combustion with an additional after burner for smoke free completion of the combustion process.

Recirculated combustion gases are used for predrying of the incoming refuse. A dust collector and air washer are used for final dust separation. The ashes are removed by conveyor from the water filled clinker chill pit below the rotary cone. Waste heat boilers are not used with this type of incinerator.

Design Practice

Apparent differences between refuse in Europe and that in this country can be resolved if one analyzes the method of heating value analysis used here as compared to that used in Europe. Generally we know that 1.0 kcal calorie per kg equals 1.8 Btu/lb, but the fact that in Europe the low heating value is used instead of the high heating value as commonly used in this country, is relatively unknown. This difference becomes quite considerable when fuels with high moisture content are used as refuse. This discrepancy in heating value determination accounts for the apparent low heating value of municipal refuse from European cities.

An oversimplified example illustrated in Table II. may clarify this point. The HHV = 3,550 kcal/kg was determined calorimetrically with the dry substance. The LHV was determined by the difference between the HHV and the inherent moisture in the fuel. “LHV available” results from the difference between LHV and the latent heat of evaporation of the free moisture contained in the fuel.
If these same values are interpreted in Btu's we arrive at the following values:

- LHV: \(3,550 \text{ kcal/kg} \times 1.8 = 6,400 \text{ Btu/lb}\)
- HHV: \(3,300 \text{ kcal/kg} \times 1.8 = 5,950 \text{ Btu/lb}\)

Table II shows the metric values whereas Table III indicates the equivalent losses in the foot pound system. The last line of Table III represents a typical refuse analysis as found in this country. Table IV gives a list of refuse composition from various cities.

It should be noted that the heat loss in ashes has been disregarded as insignificant for the sake of simplicity. This method of analysis limits the fuel to cellulose and does not take any fats, oils, or plastics into account. For a quick interpretation this may be satisfactory. On this basis the refuse heating values

### Table II

**Influence of Moisture for Refuse with 85 Per Cent Cellulose and 15 Per Cent Ashes (Metric System)**

<table>
<thead>
<tr>
<th>Moisture Content</th>
<th>&quot;LHV Available&quot;</th>
<th>Inherent Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per Cent</td>
<td>Per Cent</td>
<td>HHV - LHV</td>
</tr>
<tr>
<td>0</td>
<td>3300</td>
<td>7</td>
</tr>
<tr>
<td>20</td>
<td>2510</td>
<td>29</td>
</tr>
<tr>
<td>40</td>
<td>1720</td>
<td>51</td>
</tr>
<tr>
<td>60</td>
<td>936</td>
<td>73</td>
</tr>
<tr>
<td>80</td>
<td>148</td>
<td>95</td>
</tr>
</tbody>
</table>

### Table III

**Influence of Moisture for Refuse with 85 Per Cent Cellulose and 15 Per Cent Ashes (FT LB System)**

<table>
<thead>
<tr>
<th>Moisture Per Cent</th>
<th>Burnable Per Cent</th>
<th>Non-Burnable Per Cent</th>
<th>HHV in Cellulose Btu</th>
<th>Lat. Heat of Vaporization</th>
<th>&quot;LHV Available&quot;</th>
<th>Inherent Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>85</td>
<td>15</td>
<td>6400</td>
<td>5950</td>
<td>0.</td>
<td>5950</td>
</tr>
<tr>
<td>10</td>
<td>76.5</td>
<td>13.5</td>
<td>5360</td>
<td>97</td>
<td>5263</td>
<td>1137</td>
</tr>
<tr>
<td>20</td>
<td>68</td>
<td>12</td>
<td>4760</td>
<td>194</td>
<td>4566</td>
<td>1834</td>
</tr>
<tr>
<td>30</td>
<td>59.5</td>
<td>10.5</td>
<td>4170</td>
<td>291</td>
<td>3879</td>
<td>2521</td>
</tr>
<tr>
<td>40</td>
<td>51</td>
<td>9</td>
<td>3575</td>
<td>388</td>
<td>3187</td>
<td>3213</td>
</tr>
<tr>
<td>50</td>
<td>42.5</td>
<td>7.5</td>
<td>2980</td>
<td>485</td>
<td>2495</td>
<td>3905</td>
</tr>
<tr>
<td>60</td>
<td>34</td>
<td>6</td>
<td>2380</td>
<td>582</td>
<td>1798</td>
<td>4602</td>
</tr>
<tr>
<td>70</td>
<td>25.5</td>
<td>4.5</td>
<td>1785</td>
<td>679</td>
<td>1106</td>
<td>5294</td>
</tr>
<tr>
<td>80</td>
<td>17</td>
<td>3</td>
<td>1192</td>
<td>776</td>
<td>416</td>
<td>5984</td>
</tr>
</tbody>
</table>

25 | 50  | 25  | 3500 | 243  | 3257 | 3143 | 49.2 |

### Table IV

**List of Refuse Composition from Various Cities**

<table>
<thead>
<tr>
<th>City</th>
<th>Season</th>
<th>Moisture Per Cent</th>
<th>Non-Burnable Per Cent</th>
<th>Burnable Per Cent</th>
<th>LHV KCAL/KG.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milan</td>
<td>Summer</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>1100-1200</td>
</tr>
<tr>
<td>Basel</td>
<td>Winter</td>
<td>32</td>
<td>42</td>
<td>26</td>
<td>1200</td>
</tr>
<tr>
<td>Cologne</td>
<td>Winter</td>
<td>19</td>
<td>55</td>
<td>26</td>
<td>1070</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>Summer</td>
<td>34</td>
<td>30</td>
<td>36</td>
<td>1650</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>1050</td>
</tr>
<tr>
<td>Stockholm</td>
<td>Summer</td>
<td>30</td>
<td>20</td>
<td>50</td>
<td>1700</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>50</td>
<td>5</td>
<td>45</td>
<td>1500</td>
</tr>
<tr>
<td>Buenos Aires</td>
<td>Summer</td>
<td>58</td>
<td>13</td>
<td>29</td>
<td>1060</td>
</tr>
</tbody>
</table>
established in Europe apply very well to the refuse found in this country.

A second discrepancy concerns the quantity of heat that can be recovered from refuse. Quantities of steam generated per lb of refuse in some European installations are shown in Table V together with other valuable design and performance data.

<table>
<thead>
<tr>
<th>Installation</th>
<th>Paris</th>
<th>Munich</th>
<th>Duesseldorf</th>
<th>Hamburg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refuse burning rate</td>
<td>18,800</td>
<td>56,000</td>
<td>22,000</td>
<td>22,000</td>
</tr>
<tr>
<td>Evaporation rate</td>
<td>1.32</td>
<td>1.43</td>
<td>1.12</td>
<td>1.50</td>
</tr>
<tr>
<td>Boiler heating surface</td>
<td>1.25</td>
<td>combined with coal firing</td>
<td>1.53</td>
<td>1.71</td>
</tr>
<tr>
<td>Grate width</td>
<td>8.0</td>
<td>22.25</td>
<td>10.0</td>
<td>5.6</td>
</tr>
<tr>
<td>Grate length (Proj.)</td>
<td>22.0</td>
<td>27.0</td>
<td>27.5</td>
<td>36.0</td>
</tr>
<tr>
<td>Grate area</td>
<td>176</td>
<td>601</td>
<td>275</td>
<td>200</td>
</tr>
<tr>
<td>% Opening</td>
<td>16</td>
<td>10</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>% Burning rate (Grate loading)</td>
<td>107</td>
<td>93</td>
<td>80</td>
<td>110</td>
</tr>
<tr>
<td>CO₂ at boiler exit</td>
<td>10.0</td>
<td>13.5</td>
<td>12.5</td>
<td>10.0</td>
</tr>
<tr>
<td>Stock temperature</td>
<td>437</td>
<td>338</td>
<td>520</td>
<td>392</td>
</tr>
</tbody>
</table>

It is interesting to note that the European refuse collection rate of 1.6 lb/day per capita lies considerably below the 4.0 lb/day per capita rate in this country. If we assume a more conservative value of 3.5 lb/day per capita and use an evaporation value of 1.50 lb/lb of refuse then it is possible to estimate the heat recovery for a hypothetical town with 50,000 inhabitants as follows:

- Population 50,000
- Refuse collection rate 3.5 lb/capita/day
- Average daily refuse collection 175,000 lb/day
- Evaporation rate 1.50 lb/lb refuse
- Average steaming rate 11,000 lb/hr.

With a proper auxiliary firing arrangement as shown in the illustrations for the Munich and the Stuttgart Power Plants it seems feasible to obtain a very useful and economic method of heat recovery. Such a scheme may be utilized in many ways depending entirely on local conditions.

The dividend from heat recovery is of course small when compared with the real dividends - smokeless combustion, the clean stack discharge, unpolluted waters, and improved environmental conditions for the surrounding urban population.

**Summary**

1) Travelling Grates as shown in Fig. 11 do not promote turn-over of the refuse bed. All burning takes place on the surface of the fuel and wet refuse may pass through the furnace without even being charred. Several methods of refuse agitation in connection with travelling grates have been attempted to obtain better results (See Fig. 6).

a) Mechanical agitators above the grate are subject to high furnace temperatures and require maintenance and repair.

b) Several travelling grates arranged in steps create a refuse turn-over as the burning mass drops from step to step. This results in considerable dust being released and increases the fly-ash carry over.

c) Combination of mechanical agitators and step wise arrangement of travelling grates present the same problems.

2) Reciprocating Grates (Figs. 1-3 and 10). Both the arrangements shown are handicapped by width limitations due to the feeding of the refuse into either a rotary kiln or a circular slag generator. The resulting pile-up of refuse requires a high under grate air pressure and results in disturbed fuel bed with considerable carry-over of fly-ash. Considerable wear on the reciprocating grate sections has also been reported. In one case the movable grates had to be replaced every 9 months.
3) Reverse Acting Martin-Type Grates (Figs. 4, 5 and 15). The reverse grate operation appears to do a good job of turning the refuse bed several times while the material traverses the grate length with a minimum of carry-over. The burnout is reported to be very thorough. The sliding grate sections have ground surface face sections. It remains to be seen whether the ashes will cause excessive wear on these surfaces.

4) The Multiple Rotating Drum Grate (Figs. 7-9 and 14). The low turbulence rate with thorough turn-over of the refuse and total absence of friction between the grate cylinders result in a very satisfactory performance and thorough burnout. 13,000 hours of maintenance-free grate operation have been reported.

It is interesting to note that the Martin grate and the Duesseldorf grates have been selected for performance comparison at the new plant for the City of Stuttgart. The operating results will be watched by the entire industry with a great deal of interest (Figs. 14 and 15).

Conclusions

The incinerator firing methods described indicate the present trend of European design concepts. These concepts are summarized below:

1) Magnetic separation of iron from refuse before the furnace is not desirable as cans, wire and springs promote better aeration for combustion.

2) Grates should be kept as wide as practicable for a minimum refuse bed thickness. This will reduce the under grate air pressure and consequently reduce the amount of dust and fly-ash raised in the furnace.

3) Practically all units with capacities of 5 tons per hour and over are furnished with waste heat boilers.

4) The rigid European dust emission specifications of 0.15 to 0.25 lb/per 1000 lb gas at 50 per cent excess air make the use of electrostatic precipitators mandatory.

5) The use of water sprays for dust elimination is considered unsatisfactory.

6) Auxiliary ignition burners are used for small installations only, as most of the larger jobs operate on a continuous basis.

7) Heat utilization is in most cases for power generation in combination with municipal district heating systems.

The design of completely water cooled furnaces with full heat utilization and wide grates is essential to obtain good combustion with minimum turbulence and carry-over of dust from the grates. For practical reasons the excess air must be limited to 50 per cent to avoid difficulties and high cost of the dust collection system.

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References

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