An Appraisal of Refuse Incineration in Western Europe

CASIMIR A. ROGUS
Department of Sanitation
New York, New York

Abstract

European incineration of community refuse has reached an advanced state of the art. The author visited 13 large modern incinerators in 7 countries. The three most noteworthy operating plants are described, with emphasis on steam generation, low dust emission from the stacks, and principal features of design. Applicability to American practice is evaluated.

Introduction

The mission of a refuse incinerator is to burn down effectively all of the combustible content of the community's solid wastes at minimum cost and without creating health hazards or aesthetic nuisances. The end residue must be free of burnables and putrescibles so that its disposal, usually in a sanitary landfill, will not create, in turn, health and odor problems or pollute the water aquifers. The exhaust gases must be free of air pollutants. Finally, the incinerator site must be kept clean and the operation must be noiseless, dustless and odorless. The fulfillment of this mission is particularly important to large, densely populated communities where logically the plants and furnaces are large sized and usually located in built-up areas. The disposal problems of smaller communities with their wide open spaces are not as exacting and solutions are more readily achieved. Accordingly, the discussion that follows is confined to plants over 1,000 ton per day capacity with furnaces of 200 ton per day capacity each or larger.

It is a matter of record that American incinerator practice has made unprecedented improvements within the last generation. Nevertheless, it is also a matter of record that as yet our incinerators have not reached the finesse of design, the sophistication of controls, and the automaticity of operation now so common-place in much of our power-plant work. Coincidentally, European incinerators have been reported to have incorporated many major improvements and drastically different concepts. The objective of this paper is to examine these improvements and new concepts and to evaluate their applicability to American practice — all within the framework of the aforementioned mission.

Europe's Refuse

A discussion of Europe's refuse is pertinent. Like ours it is progressively increasing in amounts of output and gradually changing in composition and characteristics. Fig. 1 shows composite curves plotted from data obtained from 7 large cities. By projecting the data to 1966, it will be noted that their per capita total collection is about 725 lb per year as compared with today's U.S.A. median of 1435 lb. On the other hand their unit weight has decreased to 390 lb per cu yd — still substantially above our median of about 215 lb per cu yd. Fig. 2 shows a fairly typical breakdown of their refuse into its most significant components over a 12 month period. Obviously, their much higher ash and moisture contents largely account for their higher densities and lower calorific values as shown in
However, in most instances their basic design assumptions prudently anticipate considerably higher outputs and calorific values and lower ash, moisture and putrescible content. In summary, European refuse has lower calorific values, is more difficult to burn, and contains a much higher proportion of fines and abrasives.

**Incinerator Types**

Our discussion is based on personal inspections and discussions with my counterparts at 13 large modern incinerators in 7 separate European countries. Although 5 types of incinerator systems were observed and studied on 3 separate trips, only the 3 most noteworthy designs are reviewed herein. These are:

1. the DÜSSELDORF rotary-drum system,
2. the MARTIN reverse-reciprocating-grate system,
3. the VON ROLL step-down reciprocating system.

One thing that their incinerators have in common is the utilization of the generated heat for steam and/or power production. In most instances the heat energy from refuse is only incidental to the disposal of such refuse.

**Performance**

Obviously the performances varied from city to city with the many local circumstances. For our purposes, however, their accomplishment of the missions previously cited can be categorized as follows:

**Effectiveness of Combustion**

Notwithstanding the relatively poorer quality of European refuse, it was repeatedly reported and personally observed that their combustion efficiencies were in excess of 90 per cent. The residue, amounting to about 35 per cent by weight of refuse burned, contained from 3 to 5 per cent combustibles and from 0.01 to 0.05 per cent of putrescibles.

**Exhaust Gases**

As already noted European refuse has a very high dust content which obviously contributes to a high particulate count in the raw gas. Nevertheless, their permissible stack emissions are limited to about 0.20 lb of particulates per 1,000 lb of flue gas, corrected to 50 per cent excess.
FIG. 3 CALORIFIC VALUES

air. Actual emissions are well within these limits with overall cleaning efficiencies exceeding 97 per cent. The legal restrictions on noxious gases are not too well defined. Where health problems might arise, however, as in the case of sulphur dioxide, such gases are required to be discharged at high levels. Their effective stack heights range from 350 to 600 ft above ground level.

General Cleanliness
The visited plants and their immediate sites were generally cleaner and freer of dust and odor nuisances than those prevailing in America. Some, as a matter of fact, were surrounded by high-class apartment house developments.

Costs - Capital and Operating
An accurate determination of costs and their comparison, (1) among European incinerators, and (2) with American incinerators, is impossible. Differences in unit costs of labor and materials, types and extent of auxiliaries used, varying degrees of sophistication in design, and many other local circumstances and refinements in construction and operation make cost comparisons almost chaotic. Nevertheless, some useful generalizations can be made, some based on factual data and some on the author’s observations and queries.

Capital Costs. The European incinerators reported on include such costly elements as steam and power generation, electrostatic precipitators, oversized wastes processing equipment, boiler water treatment, and residue screening and salvaging mechanisms. These elements are not generally included in American practice. Table 1 attempts to present capital costs, corrected to 1965 index, for plants on which some such information could be obtained. The last line of this table shows corresponding information for the six newest incinerators in New York City. It will be noted that the approximate costs in Europe ranged from $6,000 to $16,000 per ton per day. Their median cost of $10,000 is surely in line with or less than New York City’s $8,000, if proper credit is allowed for their usual oversizing of plant components and the many extra items and auxiliaries.

Operating Costs. These costs are most difficult to pin down either in Europe or in America. Few cities maintain continuous records pertinent to a direct cost appraisal as is done in New York City. From the meager data obtained we constructed Table 2. Amortization costs were excluded since they involve too many major variables and practices in their calculations. It will be noticed from this table that:

1. Their plant operating factor (ratio of actual tonnage processed to theoretical tonnage capacity) is generally much lower. Since dependability of continuous round-the-clock operation is essential to satisfy the steam and electric power commitments, all of their plant components are oversized and substantial standby capacity is built in.

2. Similarly, the most common European practice is to operate 7 days, i.e. 168 hours per week, as compared with America’s 128 hours or less.

3. Their labor costs (operating, maintenance, routine repairs and plant supervision) with a median of 0.66 man-hours per ton are about 10 per cent lower, notwithstanding that this invariably included the operation and maintenance of steam and power generation, handling of oversized wastes, and producing a more thorough burn-down, but with fewer nuisances.

4. European operating costs in dollars are substantially lower, particularly if credit is given for the steam, power, residue and metals sales. This may be due in part to lower labor unit costs and perhaps somewhat higher skills and labor productivity. Mostly, however, they reflect the character and sturdiness of design which make fewer demands on maintenance and repairs. Above all, their higher mechanization and automaticity requires substantially lower manning. An optimum example of the latter is the small 44 ton per day plant in Zermatt, Switzerland. Here the refuse feeding, furnace control and ash and slag removal is handled by one man from a control pulp (overlooking the adjoining storage pit), located at the front end of the furnace.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Vienna</td>
<td>Von Roll 3 @ 200</td>
<td>Waste Oil</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>1</td>
<td>$9,600,000</td>
<td>$16,000</td>
<td></td>
<td>Difficult Foundations</td>
</tr>
<tr>
<td>Munich</td>
<td>Martin 2 @ 660, Martin 1 @ 1,060</td>
<td>Pulv. Coal</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>1</td>
<td>21,750,000</td>
<td>9,100</td>
<td>Costs Approx.</td>
</tr>
<tr>
<td>Dusseldorf</td>
<td>Drum 4 @ 250</td>
<td></td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>1</td>
<td>7,500,000</td>
<td>7,500</td>
<td>Cost incl. Bldg. for total of 6 furnace units</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>Martin 4 @ 385</td>
<td></td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>2</td>
<td>9,250,000</td>
<td>6,000</td>
<td>Steam for on-site only, El. power gen.: 10% for Inc. bal. sold</td>
</tr>
<tr>
<td>Paris (Issy-les-Moulineaux)</td>
<td>Martin 4 @ 450</td>
<td></td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>2</td>
<td>20,000,000</td>
<td>11,100</td>
<td>Highly Sophisticated</td>
</tr>
<tr>
<td>Lausanne</td>
<td>Van Roll 2 @ 200</td>
<td></td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>1</td>
<td>4,000,000</td>
<td>10,000</td>
<td>Handsome plant in midst of Apart.-area</td>
</tr>
<tr>
<td>Montreal</td>
<td>Martin or Von Roll, 4 @ 300</td>
<td></td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>2</td>
<td>12,000,000</td>
<td>10,000</td>
<td>Bids token Nov. 2, 1965</td>
</tr>
<tr>
<td>N.Y.C.</td>
<td>Travel Gr. 4 @ 250</td>
<td></td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>8,000,000</td>
<td>8,000</td>
<td>Large Subsidence Chambers</td>
</tr>
</tbody>
</table>

**TABLE 1**

**CAPITAL COSTS**

*(All plants burn mixed, unsegregated refuse.)*
TABLE 2
OPERATING COSTS
(All plants burn mixed, unsegregated refuse.)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Design Cap. per plant (ton/day)</th>
<th>Operating hr per wk</th>
<th>Operating* Factor</th>
<th>Tons Processed (tons/wkg day)</th>
<th>Mon Power (man-hr/wkg day)</th>
<th>Cost (man-hr/ton)</th>
<th>Cost** (dollars/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>600</td>
<td>168</td>
<td>70</td>
<td>420</td>
<td>384</td>
<td>0.91</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>1,000</td>
<td>168</td>
<td>85</td>
<td>850</td>
<td>564</td>
<td>0.66</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>1,540</td>
<td>126</td>
<td>70</td>
<td>980</td>
<td>592</td>
<td>0.60</td>
<td>$2.50 net</td>
</tr>
<tr>
<td>D</td>
<td>400</td>
<td>-</td>
<td>50</td>
<td>200</td>
<td>-</td>
<td>-</td>
<td>$3.50 gross</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>6 Modern, continuous-type plants***</td>
<td>1,000</td>
<td>128</td>
<td>80</td>
<td>800</td>
<td>576</td>
<td>$1.50 net</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$4.30</td>
</tr>
</tbody>
</table>

NOTE: All European inc. equipped and operated to include steam and power generation, residue processing and metal salvage.

*Operating Factor = Average actual production + Design capacity.
**Total cost exclusive of amortization.
***Average values per plant for 6 modern plants for 3 years of 300 working days each — refuse incineration only.

Plant Components

It can be concluded from the above that in comparison with our large plants the more sophisticated European incinerators burn their inferior refuse more completely and economically, with fewer nuisances and much less air pollution. A detailed discussion of their major plant components in functional sequence may help explain this broad evaluation.

Tipping

Tipping is defined as discharging of refuse from collection trucks to storage pit. Most of our large incinerators enclose the truck weighing and dumping operation in a building extension adjoining the storage pit. Such enclosures help to confine the noise and the dust and wind-blown debris raised in the dumping operation, and also give desirable protection against inclement weather conditions. Although many exceptions to this practice exist here; their use, particularly for incinerators located in the snow belt and in built-up, sensitive areas, appears to be justified. It should be added that the attendant problem of promptly removing the large masses of dust-laden air from such enclosures has not been solved satisfactorily to date.

European tipping practice differs. There the weigh house is separated while the truck discharge into the pit is made through several parallel ground level openings into the pit. These openings are either in the form of overhead trucking doors, normally closed but automated to open during the dumping operation, or in the form of individual depressed hoppers discharging into the pit by means of Tainter-type drum gates or oscillating rudder-like pushers. The overall effort is to minimize the raising and dissipation of dust in the dumping operation.

Storage Pits

As in America storage pits are of reinforced concrete construction but without surface armoring. They are, however, much larger, being generally sized from 45 to 60 hours of furnace operating time, and in one instance 168 hours. These larger capacities are undoubtedly dictated by the need for uninterrupted operation mandated by their steam-supply and power-generation commitments. In two cases (Rotterdam and Geneva) 50 per cent or more of the refuse is brought in by well-type barges. Some of their pits are of twin construction, i.e., a smaller, lower leveled receiving pit is augmented by a parallel larger, upper leveled storage pit. This dual arrangement is usually less expensive. The first pit is kept partially emptied for truck dumping by continuously transferring its contents into the second pit, whence the refuse is lifted into the charging hoppers.

The storage pit and charging floor enclosures operate under a slight negative pressure. This develops since the dust laden air is taken out of this enclosure through screened intakes located near the roof level, and after pre-filtration and pre-heating is discharged under the furnace grates as air of combustion in amounts up to 75 per cent of the total excess air used.

Oversized Wastes

Most of the incinerators visited also handled large oversized materials. These were dumped either into a
LONGITUDINAL SECTION THRU TYPICAL PLANT

1. Refuse collection truck
2. Tipping holst
3. Discharge (primary) pit
4. Storage (secondary) pit (showing estimated levels from Mon. through Fri.)
5. Working bridge crane
6. Reserve bridge crane (showing means of interchanging cranes)
7. Charging hopper
8. Rotating drum grates
9. Waste heat boilers & water cooled walls
10. Residue quenching, dewatering and discharge
11. Residue belt conveyors
12. Boiler water treatment
13. Electrostatic filter
14. Induced draft fans
15. Exhaust stock

DETAILED ARRANGEMENTS

1. Electric Drive
2. Drive coupling
3. Bearings
4. Structural Supports
5. Hollow Drive Shaft
6. Spiral
7. Steel (spider) frame
8. Grote bar keys
9. Int. grote bors
10. End grote bors
11. Air seal
12. Spring tensioned shroud
13. Air channel
14. Metal housing
15. Air zone

FIG. 4 "DRUM GRATE" INCINERATOR

119
small adjoining separate pit or into a pre-selected portion of the general refuse pit. This over-large refuse (furniture, lumber, mattresses, etc.) was raised by the crane and dumped into a large crusher system located on the charging floor. After being chewed up to a small manageable size, the material was chuted back into the common pit for processing with normal refuse.

**Crane Buckets**

Crane buckets are of larger capacity (5 to 7 cu yd), operate on a slower cycle, and mostly are of orange peel (polyp) type. The slower speeds require less power, produce less wear and tear on the pit walls and on the crane, and enable automatic weighing and recording of each bucket payload. The polyp grabs are generally preferred because of their more positive engagement of all types of refuse, including oversized materials and jumbled miscellaneous lumber, and because of reduced spillage. They appear to be more expensive, have a larger tare weight and require somewhat larger vertical and horizontal clearances.

**Cranes**

European bridge cranes appear to be similar to ours, although fixed crane control rooms — usually in same number as cranes — appear to be quite popular. These are air conditioned and fully glassed in and partially overhang the pit wall to provide good visibility to the operator. Our fixed, exposed power lines were replaced in some instances by draped, festooned type insulated cables. This arrangement presumably reduced the electrical safety hazards and the dust and maintenance problems. Some of their latest crane rails consisted of heavy steel bars welded continuously to the top cover plate of the runway girder. The use of three cranes is quite common — two for normal operation and the third as a standby unit. Their continuous re-handling of refuse and commitment to a 7 day per week operation undoubtedly mandates this set-up.

**Furnaces**

In their latest designs the combustion chamber is part of the furnace system. The end third is a shallow, rectangular structure, roofed over with a low reflector arch which clears the sloping grates by five to six feet. The front two thirds of the furnace has a high, stack-like configuration, giving a more effective flame burn-out, a more complete destruction of particulates and gases, and increased cooling and heat recovery due to water-cobbled surface areas. Furnaces are fully steel sheathed on the outside and are pierced with very few openings so as to provide optimum dust-tight construction.

In several of the latest plants the furnace walls and arches are lined inside with steel tubing, 1 to 1½ in. in diameter, placed contiguously to each other and connecting to large diameter headers near the grate level and running parallel thereto. Only the lowest 5 to 10 ft of
Refuse-incineration plant, Vienna XVI, Flötzersteg
1 Unloading hall, 2 Refuse pit, 3 Clinker pit, 4 Sludge settling tanks,
5 Furnace house, 6 Electrostatic filter, 7 Reversing filter, 8 Control desk,
9 Machine house, 10 Battery room, 11 Charging hall, 12 Depot,
13 Magazine, 14 Workshop, 15 Chimney.

FIG. 6 VIENNA INC. WITH VON ROLL RECIPROCATING GRATES

this tubing was covered with refractories — the balance
was left exposed. By maintaining the water in this
tubing at 400 F or higher the tube metals are held above
the dew point of the furnace gases. Thus the conden­
sation of these corrosive gases is prevented and tube
failures are nil.

The principal advantages of water-cooled walls are
reported to be:

1. Substantial reduction in excess air usage. Present
American practice limits furnace temperatures to about
1800 F in order to reduce slagging and to protect the
refractories. This temperature control is largely
effected by introducing cooling air, as required, thereby
introducing up to 150 per cent and higher excess air.

2. Reduction in air volumes. To illustrate, an increase
in excess air from the 50 per cent or less generally
practiced in Europe to our 150 per cent or higher will in­
crease air volumes by about 70 per cent, with attendant
materially increased costs of the larger furnaces, larger
air pollution abatement apparatus, and higher blower and
air duct requirements.

3. Reduced cost of furnace walls and arches. Our
conventional designs call for thicknesses ranging from 15
to 24 in., including very costly silicon carbide surface
refractories. European water tube walls are only 7 to 12
in. thick and built of less expensive refractories and
insulating brick, but include an exterior dust-tight steel
sheet envelope.

4. Slagging and bonding of fused fly-ash on our
refractory brick walls and arches, a costly removal and
maintenance problem, is practically eliminated.

Grates

Three types of grates were particularly observed and
studied. In alphabetical order these were:

Drum Grate System. After a 22,000 hour, low cost
maintenance operation of a pilot four-cylinder grate in an
8 ton per hr furnace installation at the old Flinger Plant,
City of Düsseldorf, the inventor and developer of
this system has under construction (about 55 per cent
finished) a new incinerator costing about $7,500,000.
This low cost — in spite of the fact that it includes
waste-heat boilers, shredding and handling apparatus for
oversized burnable wastes, and a very sophisticated
residue salvaging system — is for a complete 1,440 ton
per day plant, except for four furnaces now and two in
the future. Naturally, the new furnaces and grates are
greatly improved over those used in the test plant.
Nevertheless, a dependable appraisal of the merits of
this system must await at least 12 months operating
experience with this new plant.

The Düsseldorf installation is comprised of 7
cylinders or drums placed in series on a downward 30 per
cent slope (See Fig. 1). Each drum is 5 ft in diameter
and 10 ft long. They rotate in the discharge direction at
adjustable peripheral speeds varying from a maximum of
50 ft per hr for the first cylinder to a minimum of 16 ft
per hr in the end cylinder. The surface of each drum is
built up of serrated bars of commercial gray iron cast in
the form of arced segments and keyed to a structural
steel spider. Each drum rests separately over individual
steel compartments for purposes of zoning the input of
underfire air and the siftings discharge. The slow, varied
speed rotation of each drum subjects the refuse to a
mild continuous tumbling and agitation, with no further
need for manual stoking. The combustion of the burnable
refuse is nearly complete, the discharge of siftings is
automatic, and but little dust is entrained in the exhaust
gases. It is reported that the residue in the prototype
plant contains no more than 5 per cent burnables and
less than .03 per cent putrescibles, by weight.

Martin System. This is an adaptation by Josef Martin
of Munich of their successful lignite burning grates to the
handling and burning of municipal refuse. They now have
six large, successful installations in Europe and one in
South America. Another three large plants are under
The Martin stoker is a stepped-down grate inclined at about 30 per cent slope towards the discharge end (see Fig. 2). The grate surface is made of heavy, serrated cast iron bars anchored by keys unto a structural frame. These keys push uphill in a reciprocating action against the downward flow of the refuse. At every stroke a portion of the burning material is pushed against and under the still unignited refuse. In addition, a short relative motion takes place between adjoining bars thereby freeing any metals, wires or clinkers that may have lodged in the \( \frac{3}{4} \) in. wide intervening air spaces. The thickness of the refuse bed is controlled by a reciprocating pan-type feeding grate at the forward end, and by a variable speed clinker drum at the discharge end. Grate burning rates are about 50 per cent higher than those used in America, ranging between 90 to 95 lb per sq ft per hr. A characteristic of the Martin stoker is its short but wide furnace configuration. Underfire air is zoned enabling appropriate distribution. The siftings are pneumatically discharged into the residue compartment.

The Von Roll System. This is a product of the Von Roll Co. of Zurich, Switzerland. Over 30 installations for incinerating both residential and special industrial refuse are in being. The Von Roll Co. generally does a complete turn-key job, i.e. design, fabrication and erection. Their earlier designs have been progressively improved so that each installation differs considerably from the preceding one and no one typical plant exists.

The latest Von Roll design transfers refuse from the charging hopper via a vibrating inclined hopper—controlling the rate and assuring positive feed of the refuse through a vertical chute—onto a 20 per cent slope drying stoker. After ignition the refuse is dropped vertically about 5 ft onto the second (30 per cent slope) burning stoker. Finally it is dropped another 5 ft onto a third (33 per cent) sloped stoker to complete the burnout. The hot residue is discharged into a water trough equipped with a flight conveyor or scraper. The third grate replaces their former "clinker generator" since the latter was not fully successful, particularly in the higher capacity plants. Grates are of the reciprocating stepped-down pallet type with the underfire zoned and the siftings discharging directly into the residue trough below.

Residue Systems

The American residue discharge and handling systems are either of the batch or the continuous types. Generally the former do not provide the much needed air seals, have limited residue storage capacity, do not adequately quench and cool the hot residue, and frequently create unsanitary conditions because of the leaking of the polluted quenching waters. The continuous systems are costly, invariably operate with unsanitary surface matings of grease, scum and accumulations of putrescibles and tin cans, use large amounts of water, and their flight conveyors pose a costly maintenance and replacement problem.

Some of these difficulties seem to have been overcome in Europe through the use of automated mechanical, short-stroke pushers or short inclined conveyor systems, equipped with water seals, which after a short quenching and inclined de-watering cycle push or transfer the relatively dry residue onto more or less conventional dual rubber or steel conveyors. These rapidly transport and dump the residue into storage hoppers for subsequent further processing such as magnetic separation of metallics, crushing of clinkers, and screening to two or three desired grades.

Air Pollution Abatement

Whereas in America the problem of cleaning furnace exhaust gases is still largely unsolved, that in Europe has been solved by the use of electrostatic precipitators, occasionally preceded or followed by mechanical separators, for removal of particulate matter, and by the use of much taller (upwards of 300 ft high) exhaust stacks for the better dissipation of noxious gases and aldehydes. It must be noted, however, that these solutions have been successful there mostly because of their control of furnace excess air to 40 or 50 per cent, and their use of waste-heat boilers. This combination reduces the volume of air requiring treatment, decreases the amounts and sizes of particulates entrained in the furnace exhausts, and alleviates the formation of nitrous oxides.

Summary

It is my considered judgment that Europe has developed a number of substantial improvements because they address themselves to the following essentials for optimum incineration: 1. Continuous mechanical mild agitation and intermixing of refuse: (1) to provide maximum surface exposure, thereby propagating fire ignition and minimizing destructive distillation; and (2) to dispense with costly and troublesome manual stoking.

2. High furnace temperatures (1800 F or better): (1) accelerate the combustion process, thereby permitting a reduction in the size and costs of furnaces and grates; and (2) promote better burning of the volatiles and
particulates, thereby reducing the load on and cost of air pollution abatement apparatus.

3. Air of combustion should be held as close as possible to the optimum required (about 4 lb per lb of average refuse). Excess air should be limited to a range of 25 to 50 per cent to promote most effective burning and to minimize the entrainment of particulates.

4. The high flames characterizing the burning of refuse require high combustion chambers to provide a long retention of and turbulence for the volatiles, gases and particulates with attendant more complete combustion.

5. Since furnace temperatures in excess of 1800 F promote slagging, and the softening and erosion of refractories, this temperature should not be exceeded—an undesirable solution. A better solution calls for improved refractories or water-cooled walls.