Design of the Northwest Incinerator for the City of Chicago

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ABSTRACT

The 1600-ton/day Northwest Incinerator now under construction in Chicago is described. This plant is the first precipitator-equipped, refuse-burning, water-walled-furnace, steam-generating incinerator to be bid on in the United States and is being closely followed by the construction of at least four others. The application of this type of equipment in American refuse-burning practice is becoming firmly established.

The paper primarily covers the basis for design of the plant. The general arrangement of facilities and the engineering reasons for the plant capacity and for the type of furnaces and air-pollution-control system specified are presented. The nature of the equipment and the owner's schedule imposed special requirements on the construction contract arrangement, and these arrangements are also covered in detail.

INTRODUCTION

As of October 1969, construction of the new, 1600-ton/day, water-walled furnace, electrostatic precipitator-equipped Northwest Incinerator in Chicago is approximately 40 percent complete. When completed, the plant will be the largest municipal incinerator in service in the Western Hemisphere.

OVERALL REFUSE-DISPOSAL PROBLEM

Some background on the City's refuse collection and disposal practices as they have developed over the years should be given before discussion of the design of the Northwest plant. First, the municipal-refuse-collection service provides for residential wastes only. The service includes multifamily dwellings of up to four individual dwelling units. Larger apartment houses, commercial establishments, and industrial plants receive neither municipal collection nor disposal services. Accordingly, the municipally operated refuse trucks make no pickups in the downtown areas. Private or contract haulers serving large residential, commercial, and industrial establishments must also use privately owned disposal facilities. The refuse burned in the municipal incinerators is, therefore, confined to residential solid wastes only.

Of the 9000 ton/day of refuse currently generated by the 3.5 million people in the City, about 4800 ton/day is collected and disposed of by municipal operations.

As a result of this operating method, the types and quantities of bulky refuse occurring in the waste may be quite different from those found in other parts of the country. The municipal service includes collection of residential bulky refuse, such as appliances, furniture, mattresses, rolled carpets, storm sash, doors and screens, automobile tires, and similar material. Each residential area in the City is serviced approximately once every second week by an open truck collecting bulk refuse. Some park wastes such as leaves, trees, and shrub trimmings are also handled by the municipal incinerators, but most of the park refuse collected is burned in mobile incinerators operated by the Chicago Park District.
Concentrations of demolition debris and construction wastes are not delivered to municipal plants.

The scarcity of land in the Chicago area has created a long-standing need for municipal incineration. The Northwest Incinerator is the fourth plant to be constructed by the City to serve its needs, and a fifth plant is now in the preliminary planning stage.

Sampling and analysis programs to determine the characteristics of the wastes being delivered to incinerators have been conducted from time to time. Calorific tests based on sampling conducted immediately before design indicated a lower heating value of 4000 to 4200 Btu/lb on a moisture and ash-free basis. Some samples showed an upper limit of 4625 Btu/lb. When converted to the more commonly used higher heating value basis, this upper limit provides a basis of design for present day refuse of 4900 Btu/lb. It is expected that refuse heating values will continue to increase in the future, and a value of 5000 Btu/lb was used as a basis for rating for the Northwest Plant. Provision has been made in the design for the acceptance of refuse of higher heating values, although at reduced throughput rates.

### Present Refuse-Disposal Methods

In addition to its present three incinerators and its fourth under construction, the City currently operates a sanitary landfill adjacent to the Calumet incinerator in the southeastern section of the City. The average haul distance to this site is 25 miles round trip, with the maximum haul distance 40 miles round trip. A transfer station at the Medill incinerator is used to accumulate waste designated for the Calumet landfill. The landfill is presently reaching the limit of its capacity and is scheduled to be closed by about March 1970, coincident with the scheduled commencement of operation for the first two units at the Northwest Incinerator.

As previously mentioned, the Northwest Incinerator will be the fourth incinerator for the City when it goes into its initial operating stage in 1970. The first municipal plant, the Medill incinerator, was built in 1955. This plant serves the northern side of the City and is comprised of four 180-ton/day refractory-lined, batch-fed furnaces aggregating a total installed capacity of 720 ton/day. The furnaces are equipped with mechanically operated rocking grates. Three 5-ton travelling bridge cranes, each equipped with a 3-yd³ bucket, transfer refuse from the 4250-yd³ storage bin to the furnaces. Flue gases are passed through a water-spray chamber to assist in fly-ash removal and then pass to two 250-ft brick stacks.

The second plant built was Calumet, which opened in early 1959 and serves the southern and southwestern sections of the City. This is a 1200-ton/day plant comprised of six 200-ton/day, refractory-lined furnaces. The furnaces are of the batch-feed type and are equipped with mechanically operated rocking grates. Steel settling tanks and a wet-baffle chamber are used to limit air pollution. This system combines the function of fly-ash removal and also acts as a clearwell for separating fly-ash solids from the recirculated water supply. The Calumet plant is served by three 250-ft brick stacks.

The third incinerator built by the City is known as the Southwest Incinerator and serves the central and southwestern sections of the metropolitan area. This plant, which opened in December 1962, is also of a 1200-ton/day capacity but is comprised of four 300-ton/day, Volund-type, continuous-feed furnaces. Fly-ash collection is accomplished in a manner similar to that used at the Calumet Incinerator. The plant is also equipped with four 50,000-lb/h, downstream waste heat boilers, which reclaim heat from the furnace-stack gas and generate steam, which is sold to a nearby private customer on a contract basis. The Southwest Plant is served by two 15-ft (i.d.) x 250-ft high brick stacks, which are the largest incinerator chimneys in the United States at this time.

In conjunction with its incineration operations, the City has been active in the research on the use of shredders for refuse-size reduction. The construction of the Goose Island bulk-refuse-reduction plant is nearing completion at this time, and is expected to be operating by December 1969. This facility will serve as a collection and shredding station for domestic bulk refuse from the central and western parts of the City. The primary equipment for this plant is a Pettibone-Mulliken Hammermill shredder, Model 6080. The unit will be driven by an 800-hp electric motor and will have a shredding capacity of 35 ton/h of domestic bulk refuse. A system of conveyors and a shredded-material storage hopper is provided. Shredded material will be transferred to the Southwest and Medill Incinerators for burning.

The Northwest Incinerator will also contain a shredder similar in size and capacity to the Goose Island unit. The feed conveyor for the shredded material will be located at the dumping floor level and a transfer conveyor located beneath the shredder will convey the shredded material to a discharge conveyor, which will carry the material into the
refuse storage pit. The shredded material discharged from this conveyor will pass over a magnetic drum for separation of ferrous metals.

The City has also done some experimental work with the compressing and baling technique for size reduction of raw refuse. In November 1968, a Logemann press was set up at the Calumet Incinerator under a program partially financed by a grant from the Department of Health, Education, and Welfare. The machine was given to the City by a corporation and is capable of producing 500-lb bales of compressed refuse. The machine was set up to compress a limited number of bales, which were used for study purposes, the results of which have not been published at this writing.

DETERMINING CAPACITY OF NEW PLANT

For a period of many years, the Bureau of Sanitation has kept records of refuse quantities collected in various parts of the City. These data are kept on the basis of the routes of the individual trucks, so that detailed knowledge of the refuse generated on each route is available. The location of incinerators has been planned to minimize haul distances for the trucks, and the capacity of the plants is established to suit the refuse quantities being generated in the areas that they are to serve.

The overall plan is such that the City's total needs will require the construction of the previously mentioned additional incinerator. The overall study that defined the need for the five incinerator plants was made by Mr. M. A. Noel, Engineer of Sanitation, in 1955. Prior to this time, the City had been using landfill sites, which had been available within the City. For some years, this has not been the case, and, with the closing of the Calumet landfill operation, refuse disposal by this method may be completely terminated.

A map showing the locations of these plants — the Northwest Incinerator, the Calumet sanitary landfill and the Goose Island shredding station — is shown in Fig. 1.

BASIC PLANT ARRANGEMENT

When design studies were initiated in 1966, the City's preliminary and budget planning for the Northwest Incinerator visualized a 1200-ton/day facility comprised of four 300-ton/day refuse-burning systems. It had been proposed initially that these systems would be of the Volund type similar to the Southwest plant, which had proven to be very successful in operation. At the same time, however, the refuse generation rate in the area to be served has grown, and increasingly stringent air-pollution-control regulations would very possibly influence the selection of furnace type for the new plant. Instructions were received from the City to investigate four alternate types of refuse-burning systems, as delineated in Table 1.

The basic arrangements of these systems are indicated in Figure 2.

Based on the 300-ton/day furnace size initially visualized by the City and on a design fly-ash emission rate of 0.10 grains of particulate/st ft³, an economic comparison of total refuse-burning system owning and operating costs was developed as shown in Table 2.

Before reading Table 2, the reader should note the following discussion carefully. The consultant's comparisons of the several systems were confined to examining those features of each system having an
effect on the costs of ownership and operation of the completed facilities. Equipment first costs, requirements for water and power, and variations in operating and maintenance labor requirements were then the items of concern. For these purposes, the term, “refuse-burning system,” is defined to include only that equipment between the furnace charging chute and the induced-draft fan outlet. Equipment costs, therefore, do not include the traveling bridge cranes, the residue-handling system, or any building service equipment. Also not included are construction costs for the building, chimneys, utilities, sitework, or real estate. Labor costs are also only those that would vary from system to system and do not include crane operators, supervising personnel, residue handlers, weigh clerks, and most of the maintenance staff.

Following completion of these studies, comparison of the economic data with studies previously made by the consultant for larger furnace units indicated the desirability of considering the larger furnaces. These larger units were also desirable because of the fact that the duty of the new plant was to be 1200-ton/day based on the most recent quantity determinations and that allowance should be made for outage of one of the four units installed. Additional economic comparisons were therefore made for alternate water-walled and refractory-lined furnace systems in 300-, 400-, and 500-ton/day capacities. The results of this investigation are shown in Table 3. (The same limitations on the definition of cost for Table 2 are, of course, also applicable to the Table 3 data. The currently estimated total project owning and operating costs are presented in Table 4, and comparison will show the differences between total and “system variable” costs.)

It should be noted that none of the alternates considered included the use of a wet scrubber for air-pollution control. The reason for this exclusion was a firm position on the part of the City’s Department of Air Pollution Control, indicating that a visible steam plume from the incinerator stacks would not be acceptable. Inasmuch as it was not desired to apply an unproven system for control of the plume that otherwise would be expected from a wet scrubber, it was mutually agreed between the

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Table 1
Alternate Refuse-Burning Systems Considered

<table>
<thead>
<tr>
<th>System Designation</th>
<th>Stoker Type</th>
<th>Furnace Type</th>
<th>Dust Collector Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended System</td>
<td>3-section traveling grate</td>
<td>Water-walled</td>
<td>Precipitator</td>
</tr>
<tr>
<td>Alternate A</td>
<td>Reciprocating grate</td>
<td>Water-walled</td>
<td>Precipitator</td>
</tr>
<tr>
<td>Alternate B</td>
<td>Reciprocating grate</td>
<td>Single-chamber Refractory-lined</td>
<td>Precipitator</td>
</tr>
<tr>
<td>Alternate C</td>
<td>3-section traveling grate</td>
<td>Single-chamber Refractory-lined</td>
<td>Precipitator</td>
</tr>
<tr>
<td>Alternate D</td>
<td>Reciprocating grate</td>
<td>Volund</td>
<td>Precipitator</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>System</th>
<th>Furnace and Gas Cleaning Equipment</th>
<th>Estimated Equipment Costs*</th>
<th>Estimated Annual Costs</th>
<th>Total Fixed Changes and Operating Costs ($/yr)</th>
<th>Estimated Cost/ton Burned ($)</th>
<th>Fly-Ash Emission Gr/st ft *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended</td>
<td>Water-wall and precipitator</td>
<td>1,149,000 3,830</td>
<td>10,500 None 13,985 81,579 106,064 1.24 0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate A</td>
<td>Water-wall and precipitator</td>
<td>1,099,000 3,364</td>
<td>11,300 None 13,985 71,369 96,924 1.13 0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate A European</td>
<td>Water-wall and precipitator</td>
<td>1,200,000 4,000</td>
<td>11,200 None 13,985 85,200 110,385 1.29 0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate C</td>
<td>Refractory walls, spray chamber, and precipitator</td>
<td>675,785 2,253</td>
<td>24,510 10,822 29,375 47,981 112,688 1.32 0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate B</td>
<td>Refractory walls, spray chamber, and precipitator</td>
<td>588,946 1,963</td>
<td>25,336 10,822 29,375 41,815 107,348 1.26 0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate B European</td>
<td>Refractory walls, spray chamber, and precipitator</td>
<td>816,475 2,722</td>
<td>31,092 10,822 29,375 57,970 129,257 1.51 0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternate D</td>
<td>Refractory walls, spray chamber, and precipitator</td>
<td>712,841 2,376</td>
<td>26,161 10,822 33,650 50,612 121,245 1.42 0.10</td>
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</tbody>
</table>

* Equipment costs include elements of one complete refuse-burning system as described in text. This includes the cost of steam-condensing equipment.
† Annual power cost is based on 6832 h at $0.015 kWh. Water-wall system uses steam power for induced-draft fans, boiler feed pumps, and forced draft fans.
‡ Water cooling is based on 6832 h at $0.22/1,000 gal.
§ Maintenance costs include allowances for refractories, boiler feedwater treatment, packing, lubrication, and stoker parts. Labor cost is taken as an annual charge of $8,000/year for one operator per unit. Cost of labor and operation is based on 1200 tons/day.
\[\text{Amortization} = \text{interest} \times 4\% \times \text{principal repayment over 20-year period.}\]
\[#\] Grains of particulate per standard cubic foot.

NOTE: This data is not for use in construction estimating. (See text.)
consultant and the City that scrubbers would not be considered.

The data shown in Table 2 and 3 show that where stringent air-pollution-control criteria are applied, the use of a water-walled furnace is economically preferable to a refractory furnace in the furnace sizes indicated. The data also indicate that a change in capacity from 300- to 400-ton/day furnace systems was desirable. On June 1, 1967, therefore, the City directed the consultant to proceed with final design based on these two conclusions. At this time, the City also indicated that every possible step should be taken to accomplish a construction start at the earliest possible date and indicated its desire to get equipment on order as soon as was feasible.

In accordance with these conditions, it was proposed that the work be initially divided into at least two contracts, the first of which would include all equipment from the refuse charging chute to the induced-draft fan outlet and to the residue conveyor discharge. Work was started immediately on the preparation of contract drawings and specifications for these systems. The design was completed in November 1967 and was advertised for bidding almost immediately. The contract required that a boiler manufacturer act as prime contractor and that this manufacturer be responsible for furnishing and installing, within a building to be furnished by others, the complete refuse-burning system as previously described. The contract documents at this time included heavy penalties for failure to meet the specified refuse-burning rate and for failure to obtain a specified residue quality.

**BIDDING EXPERIENCE**

Bids were received January 9, 1968, and the low bid was about $11.2 million. This bid was well above the consultant's estimate for the work, and it was determined from the bidders that large amounts had been carried in their figures as protection against the penalty clauses contained in the contract.

**Table 4**

<table>
<thead>
<tr>
<th>Estimated Total Owning and Operating Costs (Dollar/Ton Burned)</th>
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</thead>
<tbody>
<tr>
<td>Operating Costs</td>
</tr>
<tr>
<td>Amortization*</td>
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<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Revenue from sales</td>
</tr>
<tr>
<td>Steam</td>
</tr>
<tr>
<td>Salvaged Metals</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td>Net Cost (per ton burned)</td>
</tr>
</tbody>
</table>

Based on actual bid prices, which also show that installed first cost of refuse-burning system equipment is about one-half of total project cost. Note difference between these data and figures of Table 2 and 3.

**Table 3**

<table>
<thead>
<tr>
<th>Economics of Alternate Refuse-Burning-System Capacities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tons/Day Type Furnace</td>
</tr>
<tr>
<td>(Tons/Yr)</td>
</tr>
<tr>
<td>300 Waterwall</td>
</tr>
<tr>
<td>400 Waterwall</td>
</tr>
<tr>
<td>500 Waterwall</td>
</tr>
<tr>
<td>300 Refractory</td>
</tr>
<tr>
<td>400 Refractory</td>
</tr>
<tr>
<td>500 Refractory</td>
</tr>
</tbody>
</table>

* $8,000/yr labor plus $0.07 for water-wall furnace.
† 285-day year, 24h/day.
§ CRF (Capital Recovery Factor) = 0.07358.
§ $80,000 added for air-cooled condensers.
" $90,000 added for air-cooled condensers.

NOTES: All systems equipped with 3-section travelling-grate stokers.
This data is not for use in construction estimating. (See text.)
Accordingly, these penalties were eliminated, and on March 1, 1968, the refuse-burning-system contract was readvertised.

The second bid opening was on April 18, 1968. The low bid was $7,994,000. The contract was awarded to the bidder on June 17, 1968.

The Northwest Incinerator will be the first plant in the Western Hemisphere to be equipped with a Martin Stoker System. The general arrangement of the refuse-burning system is shown in Fig. 3.

STEAM SYSTEM

Specifications prepared included a requirement that the entire steam system also be furnished as a part of the refuse-burning system. This provided the potential for completely integrated responsibility for such important auxiliaries as the deaerating heaters, boiler feed pumps, condensers, and associated piping and controls.

Furthermore, it was felt that, because equipment dimensional differences varied so greatly and manufacturer's choices on locations for auxiliaries could be so different, a detailed design for the steam-piping system would not be meaningful as a part of the bidding documents. Accordingly, a flow diagram of the steam system was prepared, and the number and capacity of required feed pumps, deaerating heaters, and other steam-system auxiliaries were defined. Rigorous specifications required minimum capacities for equipment and stipulated quality-control requirements for the entire system. The drawings, however, did not define the exact sizes and locations of pipe runs, nor the locations of anchors, guides, or expansion control provisions, inasmuch as these would vary with the locations and dimensions of the equipment actually furnished and with the design of the building to be done at a later date for construction under another contract. This arrangement then placed a requirement on the contractor that is not normal in municipal construction, i.e., one of detailed design of a major system in the plant. Control over this design was retained by the City through its consultant with the normal shop-drawing procedure, but there is no doubt that when a set of bidding documents is arranged in this manner that the length of the bidding period should be set with this fact in mind. It is perhaps doubtful whether this procedure for accomplishing piping-system design is best for all concerned, and there is a good chance that the consultant would modify its practice in this respect on succeeding projects.

Because of the plant location, consideration of water-cooled condensers was not possible, and air-cooled condensers were therefore specified. The basis of the economic studies represented by
Incinerator Stoker
2 Incinerator Boiler
3 Forced-Draft Fan
4 Overfire Air Fan
5 Induced-Draft Fan
6 Economizer
7 Steam Discharge to Consumer
8 High-Pressure Condenser
9 High-Pressure Subcooler
10 Low-Pressure Condenser
11 Deaerating Feedwater Heater
12 Feedwater Pumps
13 Feedwater Treatment
14 City Water Supply
15 Continuous Blowdown Flash Tank
16 Make-Up Water Preheater
17 Concrete Blow-Down Tank
18 Auxiliary Gas Burners
19 Forced-Draft Fan for Auxiliary Burner
20 Overflow to Drain

Fig. 4 Schematic Flow Diagram for Steam-Generating Incinerator
Tables 2 and 3 included use of the steam generated by the water-walled furnace system to drive the major plant auxiliaries, such as combustion-air and induced-draft fans and boiler feed pumps. The high-horsepower, bulky-refuse shredder was also planned for installation at the plant, and the drive for this is also a steam turbine.

The boilers are designed to produce steam at a header pressure of 265 lb/in²/g, and the auxiliary-drive turbines are sized for saturated steam at this pressure. These turbines are arranged to exhaust to the low pressure steam system at about 10 lb/in²/g, and the air-cooled condensers are therefore arranged and separated into high-pressure and low-pressure assemblies. These assemblies are mounted on the roof of the building for economy in piping and to save valuable site area.

The selection of the 265-lb/in²/g header pressure is based on the fact that lower pressures would not reduce the costs of equipment and piping significantly, whereas higher pressures would have created rapidly increasing costs. Saturated steam is used to avoid the corrosion hazard associated with the higher tube temperatures that would have been required in the superheaters. Because of the low cost of steam (refuse fuel at no cost), the selection of steam pressure did not include consideration of turbine water rates and was therefore based on equipment and piping costs only. Fig. 4 is a schematic showing the steam system arrangement.

**STOKER TYPES**

In preparing the specifications for the furnace-stoker assemblies, provision was made for the use of traveling-grate, forward-acting reciprocating, and reverse-acting reciprocating stokers. Each of these stokers was to be offered within the refuse-burning-system concept, and the boiler manufacturers then took responsibility for the integration of his selected type of stoker with his proposed boiler. In allowing the types of stoker mentioned above, no major American boiler manufacturer was excluded from the project, and bids received from the boiler manufacturers offered the types of stoker noted:

1. Bidder No. 1 – Martin (reverse-acting reciprocating)
2. Bidder No. 2 – CE Traveling Grate
3. Bidder No. 3 – Detroit (forward-acting reciprocating)
4. Bidder No. 4 – Detroit (forward-acting reciprocating)

Bid prices ranged from a low bid of about $7.9 million to a high of about $12 million, with the three higher bidders closely grouped at the high end of the range.

**RESIDUE HANDLING**

Specifications for the residue-handling system were affected by the inclusion of Martin-type stokers in the bidding documents, inasmuch as this type of stoker may include a special residue-discharging device, which accomplishes the quenching (and furnace seal) function without requiring a water-filled trough, flight-type residue conveyor. The Martin system is compatible with this type of conveyor but also may be used in conjunction with pan-type or rubber-belt conveyors operating "in the dry." The bidding documents, therefore, allowed either wet- or dry-type conveyors, provided quality control and capacity requirements for both types, and left the choice to the successful bidder. For the dry-type conveyor, the specifications were limited to pan-type equipment, because it was felt that an unnecessary risk would be involved if rubber-belt equipment had been allowed for residue handling. The contractor elected to furnish pan-type conveyor equipment.

An active market in salvaged metals enables the City to sell segregated residue to contractors at their present incinerators. Accordingly, drum screens are specified to be installed at the discharge ends of the two residue conveyors. Screen tailings, mainly comprised of tin cans, are sold to a contractor who accepts the tailings at the plant. Screenings are handled separately by the City.

**BOILER AUXILIARIES**

Specifications for combustion-air and induced-draft fans included quality control and minimum capacity requirements as usual. Exact capacity, however, particularly static-pressure selection, varied significantly between possible system suppliers, so that each bidder was required to make his own selection for this equipment and its driving turbine or motor. The same consideration is applicable to the boiler feed pump total head requirement, and the specifications, therefore, provided the same flexibility for this equipment as was provided for the fans.

As previously mentioned, system economics required the use of turbine drives for major auxiliaries.
These include combustion air and induced-draft fans, boiler feed pumps, and the bulky-refuse shredder. Cranes, small pumps, air-cooled condenser fans (on the roof) and all building-service-system-equipment drives are electric motors. Use of turbine drives for boiler auxiliaries introduces the problem of provision for the initial plant start and for succeeding starts after each total shutdown of the four boilers. Initial planning by the City indicated a desire to have the flexibility to make such a total shutdown each weekend, although this may not prove to be actual operating practice. Accordingly, two of the boilers are fitted with auxiliaries having dual drives, turbine and motor. Either of these two units may be started with refuse or utility gas as the fuel and will produce the steam necessary to start other auxiliaries as required. Normal operation will probably not require the use of the motors, inasmuch as the City is planning to sell the steam produced to nearby industry, which will have a continuous demand for it. Whatever the ultimate arrangement, however, the plant is sufficiently flexible to enable operation under all conditions.

Studies were also made to determine whether the plant's steam output should be used for power generation. Under Chicago conditions, the study indicated that utility power was a more economical source than would be the case if the City operated a small power plant. The comparison was quite close, and such investigations will continue to be worthwhile, particularly for larger plants located where utility power rates are higher.

**ELECTROSTATIC PRECIPITATORS**

Air-pollution-control considerations, as previously mentioned, dictated the selection of the water-walled-furnace/electrostatic-precipitator arrangement. In specifying the precipitators, the differences between American and European design philosophy were recognized, and the requirements were so written that either type might be furnished. The specified precipitator efficiency was 96.87 percent, and it was also required that paper char, considered as a segregated constituent of the fly ash, be collected.
with the same efficiency. The specifications included, for the manufacturer's information, data on the anticipated characteristics of the ash to be collected and the rate at which, for guarantee purposes, the ash would leave the furnace. This value was expressed in terms of boiler off-gas particulate concentration and was to be taken as a fixed value by each manufacturer. This procedure fails to recognize that boilers of different design and manufacture, with widely varying gasflow arrangements, have also large variation in their capability to act as dust collectors. Future specifications for this type of system should take this into account and require only a stack-gas-particulate concentration to be met.

Location of the precipitators was established as being at the rear of the plant, supported from on-grade foundations, rather than on the roof. This location was selected primarily for architectural reasons and the City's desire for low-maintenance radial brick stacks. Economic studies indicated very little difference in cost between these two alternate arrangements. Fig. 5 shows the arrangement adopted.

The contract documents also included rigorous requirements for performance testing of the refuse-burning system. Test requirements to be met included demonstration of the systems' capability to burn the "design" refuse (5000 Btu/lb) at the specified rate while producing a grate residue containing not more than 4 percent combustible material. Refuse- and residue-sampling procedures to be used in conducting the tests were also defined, using the tentative methods established by the American Public Works Association. The contractor was also required to produce steam at the specified rate (110,000 lb/h/unit) under performance-test conditions. As awarded, the contract did not contain penalty clauses for application in the event of non-conformance to specified performance, but a performance bond in the amount of $8 million backs the contractor's 1-year guarantee. A liquidated damage clause was included for application in the event of failure to complete the work on time.

CONSTRUCTION CONTRACT ARRANGEMENT

Although the foregoing discussion has covered the major features of plant design, other features pertaining to the arrangement of construction contracts may be of interest. Because of the need for shop fabricating operations, water-walled furnaces require more construction time than do refractory furnaces. The City's need for the Northwest plant is immediate, inasmuch as a sizable sum is spent each day hauling the refuse, which will ultimately be burned at the plant, to a remote landfill. Construction scheduling was a major concern during contract-document preparation, in that it was desired to eliminate these hauling costs as soon as it would be possible to do so. It is for this reason that the refuse-burning-systems contract (Contract No. 1) is entirely separate from all other contracts on the project; by this procedure an order could be placed for the boilers well in advance of completion of the total design. Contract No. 2, covering the foundations, structural, and roof portions of the project was the second contract bid and was separated from the remainder of the project to enable a construction start prior to completion of the total design. The remaining Contracts were bid separately as documents became available. Contract No. 3 covers the traveling bridge cranes; Contract No. 4 is for general construction and site work; Contract No. 5 includes the refuse shredder, its drive, and associated materials handling equipment; Contract No. 6 covers the two 250-ft radial brick stacks. All contracts have been let at this time and were awarded as follows:

2. Contract No. 2 - foundations and structures: $2,482,818.
4. Contract No. 4 - general construction and site work: $5,466,919.
5. Contract No. 5 - shredders: $289,688.
6. Contract No. 6 - stacks: $612,000.

CONCLUSIONS

The foregoing discussion has covered the basis for design of the plant. The effects of stringent air-pollution requirements on the total plant design are significant and must be recognized by designers of large plants early in their work. The data show the decreasing importance of these considerations for smaller furnaces. The overall effect of the solid-wastes management plan on plant sizing, reliability, and construction-schedule requirements is also shown, as is the effect of the construction time requirements for water-walled furnaces.

It is hoped that the procedure for design will be of interest to others faced with a similar problem and that this report will be beneficial to the progress of incineration.
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