The technique of garbage and waste incineration has developed to such a point in the densely populated countries of Europe in the last ten years that it is now possible to build plants which meet the needs of large city populations. These are 1) the avoidance of water and air pollution by complete combustion of the refuse without causing nuisance by dust or odor, 2) low disposal costs by erecting large plants with heat utilization, 3) continual improvement of combustion techniques by making use of experience gained.

Plants in which “refuse disposal” has been converted into “refuse utilization” can be operated within a collection area comprising the equivalent of 1 to 1½ million inhabitants on an economically feasible basis, if various assumptions are intelligently applied.

The particular combustible properties of the refuse impose design and planning conditions which must be recognized and followed in the layout of the incineration plant, the exhaust gas purification systems, problems of firing control of the grate, the temperatures in the furnace, the discharge of the combustion residues, the boiler construction, etc.

Attention is drawn to the great value of operating experience in order to combat difficulties within the plant, in particular problems of corrosion.

To construct a refuse incineration plant which fulfills the multiple demands made upon it involves high costs. These can largely be recovered by suitable plant design, effective utilization of the heat of combustion liberated and by the proceeds from the sale of by-products. The remaining costs can be recovered by charges which in most cases are no higher than those of conventional landfill refuse disposal.

Two idealized cases of steam generation with refuse were investigated. How the high costs of capital, repairs and staff are offset by proceeds, with only a small part of the costs not recovered, was shown for A) electric power generation and heat supplied to a district heating network, and B) electric power generation and sea water desalting.

Three main requirements of waste incineration must be laid down:

1) Water and air pollution must be avoided by dust-free and odorless incineration of all municipal and industrial waste so that fully sterile residues which can be safely landfilled are produced.

2) A high level of technical efficiency must be obtained by applying and further developing European experience and systems.

3) Low cost must be maintained by erecting large incineration units and by intelligent use of the heat generated.
In order to meet these requirements, central incineration plants must be erected. Efforts directed towards the destruction of refuse close to the point of accumulation in technically inadequate small plants or mobile incinerators must be decisively rejected.

In a collection area of average population density, optimum results can be obtained when the planning envisages a plant for the equivalent of approximately 1,250,000 inhabitants. A typical estimate is given below for this scale of project.

In Europe the incineration of household and town refuse is regarded as a municipal responsibility, the financing of which is facilitated by state funds.

Burning industrial waste involves difficulties insofar as different combustion conditions have to be observed. Industrial participation can also be frustrated by the problem of costs. For this reason large industrial units build their own incineration plants. The disposal of waste from smaller factories is often unsatisfactory.

The various possibilities offered by modern technology for utilizing the heat released, however, converts the previous, unhygienic and costly "refuse disposal" into "refuse utilization." Under favorable circumstances, the latter becomes an economically feasible proposition if a state subsidy is forthcoming, if an appropriate charge is made for the incineration, and if the anticipated future increase in the quantity of refuse is taken into account. It therefore becomes conceivable that such functions may also be taken over by industry. People in the USA are already thinking along these lines.

With due regard to the experience available, it is possible and feasible to erect a refuse incineration plant in the neighborhood of residential areas. The choice of site can therefore be decided by those conditions which on the one hand guarantee the best utilization of the available heat of combustion and on the other hand take into account the traffic conditions. In this latter connection the considered.

2) A combustion temperature of 1580 F to 1760 F, which ensures that the combustion is odorless and that the waste gases evacuated via the stack are sterilized, should be maintained.

3) A partial vacuum should be created throughout the refuse bunker area in order to protect the surroundings from odor.

4) The waste gases should be cleaned by electrofilters and a stack height chosen such that the gaseous products of combustion are led away in harmless concentration.

5) The possibility of mixing various types of refuse of widely varying calorific value and controllable feed to the grate should be considered.

6) Continuous operation of the incineration plant by using an adjustable grate to ensure as far as possible constant load on the furnace should be maintained, in order to achieve almost steady and therefore optimum combustion conditions.

The grate must therefore satisfy a series of severe conditions. From the numerous types of grates developed in Europe, two systems have emerged and have proved themselves in large-scale incineration plants:

Reciprocating grates, arranged as inclined grates with forward or reverse feed. The movement of the fuel bed is controlled by the frequency of the reciprocating movement.

Travelling grates with agitation effect by means of several travelling grates or drums placed one after the other. The movement of the fuel bed is controlled by separately adjusting the feed of the individual sections of the grate.

Practical experience over more than 20,000 hours with both basic types has been good. Current efforts are being directed towards making the grate drive even more robust.

The following critical features affecting the design and correct operation of a refuse grate may be mentioned.

1) The shape of the feed hopper and the chute, which maintain a steady falling column of fuel, which at the same time forms a relatively airtight seal for the furnace.

2) A spreading arrangement for the refuse, so that an evenly proportioned depth of bed over the whole width of the grate is ensured.

3) Choice of the correct inclination which, in conjunction with the grate movement, ensures that the fuel bed is transported and uniformly mixed and also prevents large pieces from cascading.

4) A grate length which will ensure an adequate residence time from ignition to complete combustion.

5) Subdivision of the grate into separate sections where the movement can be independently adjusted, which

DESIGN CONSIDERATIONS

The following conditions must be fulfilled in the planning and construction of a modern refuse incineration plant:

1) The entire waste material should pass into the furnace without being sorted; only large, cumbersome elements should be broken or cut up. This is primarily a hygienic requirement, recommended so that the fermentable components of the garbage are consumed as quickly and as completely as possible.
facilitates control of the combustion characteristics over the length of the grate.

- Air distribution along the sections and across the width of the grate to adapt the air consumption to the combustion characteristics and to create a regulated air regime.
- Sufficient static pressure of the combustion air to penetrate a deep fuel bed but at not so much as to cause excessive generation of dust.
- Selection of the furnace shape to swirl the gas streams, to maintain predetermined temperatures and to ensure return radiation over the ignition zone.
- Cooling the brickwork in the combustion chamber by refractory-covered evaporator tubes as a protection against incrustations of ash and slag.
- Discharge arrangements for the combustion residues—dimensioned for bulky, noncombustible items—equipped with a large water basin for quenching and designed at the same time to prevent the ingress of unnecessary air.

A steam generator is built integral with the furnace, the heating surfaces of which line the whole furnace and radiation space. This radiation space, divided into one or two boiler passes, is dimensioned to ensure two operating conditions: 1) the exhaust gas impinging on the contact heating surfaces is cooled well below the softening point of the ash, and 2) the speeds of gas flow are low. The contact heating surfaces themselves have wide tube spacings and are equipped with powerful soot blowers for cleaning away dust and ash. In the layout of the heating surfaces particular attention must be paid to easy access and interchangeability. To reduce the costs of boiler insulation and setting, the boiler can be of thin casing or finned-tube design.

The ash particles carried away with the gases can come into contact with the heating surfaces over a relatively broad temperature range in a doughy or molten state, depending on their composition. In many plants it has been observed that as a result of this fouling, which is due to the low softening point of the ash, gas-side corrosion can occur. In most cases these attacks cease after a certain length of time, but in any case the tube wall temperatures must not be allowed to rise too high. Also the soot blowers should be operated frequently enough that deposits are removed in the incipient stage, and tube wall thicknesses increased. The chemical nature of this corrosion appears to be similar to that known from experience with certain lignite burning plants.

Previous observations and operating experience with incineration plants show that corrosion appears in the upper temperature range of approx. 1050 F to 1320 F, when, for example, the formation of molten alkali ferrous sulphates takes place, with approximately the formula K₂FE(SO₄)₃. Corrosion can also occur with the combustion of wastes with high Cl content which lead to attacks on the tube walls both by direct attack from HCl, and by the formation of liquid salt mixtures of low melting point together with sulphates.

Despite the fact that the theories concerning the occurrence of gas-side corrosion in incineration plant steam generators are not entirely confirmed, a series of measures can be incorporated at the planning stage:

- Limitation of the live steam temperature.
- Choice of waste gas temperature higher than in the case of conventional boilers.
- Dilution of corrosion-producing wastes by mixing with household wastes.
- The smallest possible proportion of fly ash in the flue gas.
- The avoidance of a reducing atmosphere of gas streams by introducing secondary air.
- Wide tube spacings and good facilities for cleaning the contact surfaces by steam soot blowers working with superheated steam.

If we take a look at the operating requirements of an incineration plant it becomes clear that automation is subject to certain limitations, especially in regard to the parts of the plant which have to be operated intermittently. This applies to the fuel feed into the hopper. The cooperation of the crane operator is essential for regulation in order to even out to some extent the quality of refuse, in particular when this is of a very diverse nature.

It is equally important to monitor the progress of combustion in order to be able to adjust the grate feed and air supply in the individual sections of the grate. This can generally be done by means of a television monitoring system and may be remotely controlled from the central control room. With the exception of the feed, all processes between the refuse bunkers and the solid residues loading station take place continuously. Yet, in comparison with a conventional boiler plant, more operating staff is necessary for an incinerator-boiler plant of same steam output.

**COMMENTS ON THE COST SITUATION**

As already mentioned, the cost of refuse incineration can be lowered by satisfactory utilization of the available heat of combustion and by the choice of large incineration units in order to reduce capital and operating costs. The
following considerations refer to a sample calculation for an urban area of 1,250,000 inhabitants.

Under US conditions 0.66 tons of waste per inhabitant-year can be expected. The assumed 1,250,000 inhabitants produce an annual refuse quantity of 826,000 tons. At 8,000 h/yr of operating time, the average combustion capacity required is 103.5 t/h. Over 90 percent availability can be achieved. This capacity is divided between two incineration units of 52 tons per hour capacity. A reserve furnace of the same size is added, thus producing an installation of three incineration units each capable of 50 percent of the needed capacity, and hence equivalent to an installed combustion capacity of 156 t/h on the whole, or 1248 tons per day for each unit. With a low calorific value of 4860 Btu/lb, the average output of heat for each of the two operating grates is 504 x 10^6 Btu/h.

The thermal efficiency of the furnace-boiler unit can be estimated at 75 percent. With live steam conditions of 598 psig and 867 F, the steam output is 652,000 pounds per hour.

The steam produced can be piped directly to consumers or passed through a steam turbine which, with a plant of the size contemplated, gives a considerable output. If the turbine is not included, then low pressure steam can be generated. However, the savings which might be expected, because the steam conditions mentioned mean that no costly alloy steels are necessary and the demands on the feedwater side are relatively small, are offset by the larger cross-sections necessary.

Utilization of the steam in a district heating network is an obvious possibility. Since the steam is produced at a regular rate, the summer excess must be fed into a condensation section. An extraction-condensation turbine is therefore necessary, so that when the outside temperature is low the steam is condensed in a heat exchanger for hot water and when the outside temperature is high it is condensed in a cold water condenser. It has also been assumed that a heat output of 496 x 10^6 Btu/h would be generated with 3800 full-load hours of operation (peak coverage by separate boiler). Likewise 3800 full-load hours of operation is the figure for the running of the cold-water condenser. This method of utilizing the heat from the refuse is designated Alternative A.

In Alternative B it is assumed that the town in question is on the coast and it is economical to supplement its water supply by desalting sea water. It may be that the region is arid or that the normally increasing fresh water requirements can only be covered by supplies from a region of high precipitation some considerable distance away. Such a combination with sea water desalting has the principal advantage that, in contrast to Alternative A, the heat can be easily disposed of an utilized at the same rate as it is produced. Thus a simple back-pressure turbine can be coupled up to the plant, a method with only relatively low costs.

Such a combination poses the condition that a site can be found which satisfies both requirements, namely the position and the distance from the collection region and the conditions for the intake of sea water and return of the brine.

For the cost estimate it is now essential to evaluate correctly the usable by-products. The following assumptions will be made:

**Heat Generated**

On the basis of an average fuel price of 30 cents/million Btu, the heat at the pumping station of the plant is evaluated at 44 cents/million Btu. The costs of the district heating distribution system are not included here.

**Electricity Generated**

Electric production must be very carefully evaluated as a proportion of the current is generated at night when general demand is low. Only the heat price of a modern large power station has therefore been reckoned with in the above fuel price and 8340 Btu/kWh. This gives approx. 2.5 mills/kWh. A subsequent calculation shows that even with this low level of compensation, the erection of a turbine and the additional costs connected with it appear to be economically justified. This value of electric current is used in both Alternative A and Alternative B, i.e independently of the number of annual hours at full load. For Alternative A it is based on the fact that heating peaks, as already mentioned, are covered by separate boilers, so that the turbine output between winter and summer varies only by ±20 percent.

In arriving at the value of electricity, the electric power consumption of the incineration plant, the turbine set, the district heating station and (for Alternative B) the sea water desalting plant are deducted, so that only the deliverable net output is used in calculation.

**Fresh Water**

The water prices attainable on the basis of present techniques using flash distillation are dependent somewhat heavily on the size of the plant. From the waste heat of the incineration process a fresh water quantity of 72,000 tons per day (approx. 19 MGD) can be produced. In other words the plant is of medium size. Despite this a large plant should be considered in the evaluation of the
water price, giving 45 cents/1000 Gal. The water price is at the outlet from the plant, i.e. distribution system costs are not included.

**Value of Scrap**

The proportion of iron in the garbage and the return on baled scrap can vary widely according to locality. Here an iron content of 7.5 percent and a value of $8/t have been assumed.

**Saving on Landfill Costs**

We have proceeded on the assumption that nothing is changed in regard to the collection and transportation of the refuse. The previous costs of refuse landfilling are very much reduced due to the fact that only 30 to 33 percent of the refuse has to be disposed of an noncombustible residue. This latter is taken into account by including an expenditure figure of $1.8/t. For the former, now unnecessary refuse dumping, $3/t have been estimated on the basis of the above figures. In order to evaluate this cautiously, the saving on landfilling used in the following will be assumed at $2/t.

The results of the technical and economic calculation for Alternatives A and B are shown in Figs. A and B respectively in the form of cost-flow diagrams. The upper half of the flow diagrams shows the expenditure on operating and capital costs and the lower half the compensation obtained from the sale of by-products and the saving brought about by doing away with landfilling. It is assumed here that the charges previously made for refuse disposal remain practically unchanged. While for Alternative A the heat generated and the sale of electric power determine the amount of compensation, for Alternative B the determining factor is the return from the desalted sea water, the sale of power being reduced because of the relatively high power consumption of the desalting plant itself.

**Explanation of the Cost Calculations**

The calculations are based on the experience of large European plants but with American conditions in relation to wage, heat prices, electric power prices, etc., taken into account. The personnel costs in Alternative A are based on a total of 50 employees for three-shift continuous operation, including the management staff. The expenditure on repairs has been assessed at 1.2 percent of the total plant costs, and the expenditure on working materials has been based on available experience. The calculation of capital costs has been based on an average figure of 8 percent for interests and amortization. This in turn is based on an interest rate of 6 percent and average working life periods of 20 years for the mechanical and structural parts of the plant. The initial outlay takes into account development costs and supplementary costs for consulting engineers' fees, taxes and mortgage interests. The above mentioned values have been inserted as compensation from the sale of by-products.

Expressed in figures, the following picture emerges:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>A</th>
<th>B</th>
<th>Million $/annum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating costs</td>
<td>1.86</td>
<td>2.22</td>
<td></td>
</tr>
<tr>
<td>Capital costs</td>
<td>2.40</td>
<td>3.44</td>
<td></td>
</tr>
<tr>
<td>Total costs</td>
<td>4.26</td>
<td>5.66</td>
<td></td>
</tr>
<tr>
<td>Compensation from the sale of by-products</td>
<td>2.36</td>
<td>3.76</td>
<td></td>
</tr>
<tr>
<td>Saving on landfilling</td>
<td>1.50</td>
<td>1.50</td>
<td></td>
</tr>
<tr>
<td>Uncovered remainder</td>
<td>0.40</td>
<td>0.40</td>
<td></td>
</tr>
</tbody>
</table>

or, referred to 826,000 tons/annum $0.48/ton (Fortuitously the same for Alternatives A and B).

In the calculations the two forms of a hypothetical multi-purpose plant were treated as complete units. The above amounts therefore include, in addition to the costs of the incineration plant itself, the proportionate costs of all ancillary installations insofar as they are necessary for the manufacture of the by-products and are contained in the investment costs.

Although in the aggregate conservative figures have been used, the result of the comparison in the example calculations is very favorable. It deteriorates immediately if the assumed full load operating hours of the district heating system and the power generating plant are reduced, or if the demand for desalted sea water is not continuous. The result deteriorates also if the capacity for doing work of the steam generator is utilized less efficiently.

Although an example calculation can to a certain degree only deal with idealized conditions, the results show that by making favorable assumptions and by correctly applying them, the unrecovered costs of an incineration plant can be very small.
FIG. A ALTERNATIVE A. COST FLOW DIAGRAM FOR DISTRICT HEATING, IN PERCENT

FIG. B ALTERNATIVE B. COST FLOW DIAGRAM FOR SEAWATER DESALTING, IN PERCENT