Total Incineration

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ABSTRACT

Total incineration is defined in this paper as the conversion of refuse to solidified slag and flue gases, the latter including mainly carbon dioxide, oxygen, nitrogen, and water vapor. The slag by-product represents the lowest possible volume of ash residue. Such stone-like slag does not require a large residue-disposal site as is necessary for the disposal of "bonfire ash" from present incinerators. Therefore, the total incineration plant can be located in a heavy industrial area and closer to the source of municipal refuse than the conventional incinerator.

A number of processes are under advanced development to accomplish total incineration. The need for supplementary energy varies among these processes. Comparisons of these processes are included. All systems can be provided with adequate air-pollution control.

INTRODUCTION

Total incineration is defined herein as the conversion of refuse to solidified slag and flue gases. In contrast to conventional incineration, which produces a "bonfire ash" at furnace temperatures in the order of 1800°F, all or part of a total incineration system must operate at temperatures approaching 3000°F in order to convert the ash residue to a liquid slag that can be drained from the furnace and solidified. This slag either can be quenched in water to form a granular material or can be allowed to cool slowly in a pit to produce a solid mass, which can subsequently be broken into lava-like lumps, similar in size to crushed stone.

Since the total incineration process yields a solid residue called slag, the process is often referred to as "slagging" incineration, and the plant, a "slagging" incinerator. Concepts of total incineration are currently in various stages of development ranging from processes that have been demonstrated in part or are at the pilot-plant stage, to concepts that seem to be feasible and practical from an industrial-technological standpoint, although they have not yet been tested or demonstrated on municipal refuse.

The principal objectives of total incineration are:

1. maximum volume reduction of solid waste (approximating 97.5 percent);
2. complete combustion or oxidation of all combustible materials, producing a solidified slag that is sterile, free of putrescible matter, compact, dense, and strong;
3. elimination of the necessity for a large residue-disposal operation adjacent to the incinerator; and
4. complete oxidation of the gaseous products of incineration with discharge to the atmosphere after adequate treatment for air-pollution control.

Fusion of the incombustible residue can be accomplished either by operating the incineration process at temperatures above the melting temperature of the ash residue or by melting the ash in a separate device subsequent to conventional incineration. Temperatures in excess of 2600 to 2800°F are required for fusion, with the actual temperature depending upon the composition of the ash in the
refuse. However, to insure adequate fluidity of the slag, a temperature approaching 3000°F should be maintained in the slag zone. Under most conditions, some limestone and possibly a small amount of fluorspar are required as flux to aid in fusion and control fluidity of the slag. Such additions reflect the composition of the refuse being incinerated, with lesser amounts of flux additives required if materials such as glass (high silica content) are removed from the refuse before charging into the furnace. The removal of metal from the refuse feed also has a considerable effect on the flux additives required.

In conventional grate-type refractory-wall incinerators, furnace temperatures are kept below 1800 to 2000°F by the introduction of excess air. The cooling effect of this excess air is desirable to avoid fluxing of refractories by fly-ash components, to reduce fly-ash adherence, to minimize refractory maintenance, and to provide thermal protection to the grate material. About 100% excess air is theoretically required to obtain temperatures under 2000°F with refuse containing 25 percent moisture. Air leakage and poor air utilization (inadequate mixing) increase the total requirement of air to levels considerably above 100 percent excess, thus increasing the volume of the flue gases and the required size of equipment for air-pollution control. In theory, refuse of less than 25 percent moisture could be burned to produce temperatures of 3000°F by operation at near stoichiometric conditions, i.e., 0 to 10 percent excess air. However, such conditions could not be maintained in a conventional furnace because of thermal damage to the grates and incinerator walls and because of the formation of clinkers.

The ability to obtain adequate slagging temperatures depends upon the following factors:

1. available heating value of refuse;
2. moisture, metal, and inert content of refuse;
3. level of excess air required for complete combustion; and
4. availability of supplemental energy.

Energy-balance calculations for producing slag from the incineration of refuse show the relationship of the variables just described as represented in Fig. 1. These curves show the supplementary heat input required to maintain the combustion chamber at 3000°F, as a function of the amount of excess air used, for various amounts of moisture in the refuse together with appropriate and corresponding available heat content of the refuse. These calculations and the resulting data presented in Fig. 1 were made on the following bases:

1. Available net heat content of combustible matter in refuse at 8850 Btu/lb (assuming 10 percent at

<table>
<thead>
<tr>
<th>Content</th>
<th>Percent</th>
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<tbody>
<tr>
<td>Moisture</td>
<td>28.2</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>44.3</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>6.7</td>
</tr>
<tr>
<td>Ash and metal</td>
<td>20.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100.0</td>
</tr>
</tbody>
</table>

Fig. 1 Supplementary Heat Requirement for Ash Fusion at 3000°F
oxidation of metals in refuse; (2) Composition [1] of the refuse according to the breakdown given in Table 1; (3) Higher heating value [1] of refuse as fired at 4520 Btu/lb; (4) Combustible and ash content of the refuse should be proportionately adjusted for higher or lower moisture level; (5) Stoichiometric air requirements at 6.34 lb of air/lb of combustible material; (6) Residue heat capacity of 0.23 Btu/lb °F and heat of fusion of 110 Btu/lb; (7) Heat loss of 5 percent through the furnace walls; (8) Thermal equilibrium of combustion products; (9) Complete combustion of all nonmetallic combustibles. Complete combustion of all nonmetallic combustibles.

Figure 1 shows that supplemental heat or energy is required to maintain fluid-slag temperatures over almost the entire range of refuse content investigated with indicated metals and inerts content adjusted for the variations in moisture content. Only the driest material, when burned with less than 10 percent excess air, can sustain furnace temperatures of 3000°F without additional heat or energy input. Although it is unlikely that complete combustion can be obtained with only 10 percent excess air because of inadequate mixing, incomplete combustion at near stoichiometric conditions is allowable in the furnace and slag zone provided that a means for securing adequate secondary combustion is available.

The above energy-balance calculations were based upon idealized and complete combustion, perfect mixing, and thermal equilibrium in the furnace. However, in actual operation, temperature differences exist, and thermal equilibrium is not attained. In addition, complete combustion may not occur in the primary chamber. Also low excess air levels or reducing conditions can be maintained in the primary chamber, with combustion completed in a secondary chamber. Only the slag fusion zone must be at 3000°F, with the other parts of the chamber at a lower temperature.

The data of Fig. 1 are useful in estimating the performance of systems in which slagging occurs in the (primary) furnace, rather than in a relatively isolated or supplementary operation. Primary-furnace temperatures will vary with the completeness of the combustion reaction and with the quantity of air used. As an example, the DRAVO/FLK incinerator (discussed later) is reported [2] to require a heat input of 1.26 million Btu/ton of refuse with 20 percent moisture and 20 percent inerts when burned with 25 percent excess air. This heat input can be provided with auxiliary fuel or with preheat of combustion air. The amount of heat agrees well with the value of about 1.1 million Btu/ton, as interpolated from Fig. 1.

If the ash residue is fused subsequent to conventional 1800°F incineration, only the sensible heat of the ash between 1800°F and about 3000°F in addition to the heat of fusion are required as supplemental energy. This energy is about 386 Btu/lb of...
ash or 170,000 Btu/ton of refuse at 22 percent ash and inert material, regardless of the refuse moisture content. Thus, with fusion of the ash residue in a subsequent and separate zone, the exit-gas temperature from the incineration step is considerably lower, with less sensible heat loss from the process.

A number of total incineration processes are currently under preliminary or advanced development. These processes vary in the amount and form of energy input required beyond the heat available from combustion of the refuse. Various approaches have been suggested to apply the ash fusion or slagging concept, and currently it is believed that the state-of-the-art is advanced to the point that total incineration must be given consideration as an acceptable method for disposal of solid waste. These total incineration processes are shown in simplified process diagrams (Figs. 2 through 8) and are identified in the following discussion:

The ORAVO/FLK incinerator process utilizes a flame chamber [3] surrounded by unburned shredded refuse, with combustion gases and fused ash discharging through an opening at the base of the combustion zone [10] (Fig. 2) with air preheated from recuperation or with auxiliary fuel.

The American Thermogen process utilizes a vertical shaft furnace [4] with the refuse oxidized in suspension, mostly in the lower portions of the furnace, with energy provided either from incandescent coke or from natural gas or both, providing an ash-fusion zone at the base of the furnace (Fig. 3).

The Sira process employs suspension burning [11] of refuse (previously shredded in three stages with most of the metal removed for salvage), with injection of the refuse with preheated air from a recuperator and augmented with gas or fuel oil as required to produce a fused ash which drains from the refractory combustion chamber [5] (see Fig. 4).

The Ferro-Tech process utilizes a grate-type incinerator furnace to devolatilize and partially oxidize refuse at temperatures of about 1800°F. The subsequent complete oxidation and fusion of the residue takes place in a short, coke-fired, cupola furnace using preheated air [6]. (See Fig. 5).

In the Torrax process, high-temperature combustion air is preheated [12] in a gas-fired [7] refractory heat exchanger. Unshredded refuse is charged into a vertical shaft furnace with the base maintained at about 3000°F by combustion of dried and incompletely devolatilized refuse with preheated air; a secondary combustion chamber completes the oxidation of volatilized gases [8]. (See Fig. 6).

The electric furnace consists of a three-phase crucible fusion furnace that converts “bonfire ash” residue from either a conventional grate-type incinerator or from a rotary kiln incinerator [13] to fused slag. (See Fig. 7).

The Oxygen-Enrichment process uses bulk liquid oxygen to obtain ash-fusion temperatures of 3000°F by enrichment of air for combustion. (See Fig. 8).

The processes just described differ in the sequence of refuse combustion, in the location and extent of the ash-fusion zone, and in the method of supplying the required supplemental energy or fuel. These processes are currently in various stages of development. The ORAVO/FLK process has been demonstrated on industrial European refuse for several years. The American Thermogen process has
been in large-scale pilot operation for several years in the northeastern United States. The Sira and Ferro-Tech processes have been partially demonstrated on USA refuse with full-scale operation contemplated. The Torrax process is under design and construction, and the electric-furnace and oxygen-enrichment types represent process concepts based on existing thermo-processing systems in successful use in industry. These processes are further described in Figs. 2 through 8. Technical and economic features of these processes as a group are discussed in this paper according to estimates and analyses by the authors. Since none of these units is yet in commercial operation in this country, considerable uncertainty exists in these estimates. As with conventional systems, capital cost estimates must be evaluated for the specific location, for a specific range of refuse composition and for the specific auxiliaries desired, e.g., steam or electric power generation.
DISCUSSION OF TECHNICAL AND ECONOMIC FACTORS

The above total incineration processes share process advantages, disadvantages, problem areas, and economics. "Advantages" and "disadvantages" refer to aspects of the process inherent in the process concept itself. "Problem areas," however, concern aspects of the process that seem troublesome but also seem tractable to engineering solution. These common characteristics are discussed below as a group rather than for each individual system. (See Table 2).

Advantages

Residue Volume Reduction

The maximum possible refuse-volume reduction (up to 97.5 percent depending upon the bulk of the original refuse and its ash content) can be achieved with fusion of the ash residue. For example, a 97.5
### Table 2
**Comparisons of Total Incineration Processes**

<table>
<thead>
<tr>
<th></th>
<th>DRAVO/FLK</th>
<th>AMERICAN THERMOGEN</th>
<th>SIRA</th>
<th>FERRO-TECH</th>
<th>TORRAX</th>
<th>ELECTRIC FURNACE</th>
<th>OXYGEN ENRICHMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Added capital cost</strong></td>
<td>None to $2000/ton depending on choice of auxiliary equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Operating cost</strong></td>
<td>None to about $2.00/ton (mostly energy)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Auxiliary energy required</strong></td>
<td>Some gas or oil</td>
<td>Coke or gas</td>
<td>Some gas or oil</td>
<td>Coke</td>
<td>Gas</td>
<td>Electric power</td>
<td>Bulk oxygen</td>
</tr>
<tr>
<td><strong>Air preheat from recuperator</strong></td>
<td>Yes</td>
<td>Possible</td>
<td>Yes</td>
<td>Yes</td>
<td>Possible</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Potential NOx air pollution</strong></td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Lowest</td>
<td>High</td>
</tr>
<tr>
<td><strong>Relative size of APC equipment</strong></td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Operating skill required</strong></td>
<td>Medium to high</td>
<td>High</td>
<td>Medium to high</td>
<td>High</td>
<td>High</td>
<td>Medium to high</td>
<td></td>
</tr>
<tr>
<td><strong>Shredding required</strong></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

* Oxygen required is 0.3 to 0.4 ton/ton refuse, depending on moisture.
percent volume reduction is equivalent to the processing of one ton or 154 ft³ of refuse with a bulk density of 350 lb/yd³ to a residual volume of fused granular material of only 3.78 ft³ with a bulk density of 110 lb/ft³. By comparison, conventional low-temperature incineration has provided average volume reductions of only 50 to 80 percent [1]; however, modern low-temperature incinerators can produce volume reductions of over 90 percent under good operating conditions (including some residue compaction).

Ash Residue Quality

All putrescible and combustible material is destroyed in the high-temperature fusion of the ash residue. The resulting slag can be solidified either rapidly in a water quench tank, or more slowly by cooling in air in a large mass after separation of the metal phase and the slag phase. Rapid quenching in water produces coarse, porous granules, together with globules of solidified metal. The slag granules are suitable for solid fill or for low-strength concrete blocks. Conversely, slow cooling is a convenient, low-cost process and can produce a stronger aggregate material.

Flue-Gas Odors

All odorous components of the flue gases can be completely oxidized if adequate mixing is realized since all of the processes involve minimum, uniform combustion-gas temperatures in the range of 1600 to 1800°F, and oxidation of odor compounds will be complete in the presence of excess air at these temperatures.

Flue-Gas Volume

Most of the processes utilize less combustion air than conventional incinerator furnaces, which require large amounts of excess air to avoid fluxing and thermal degradation of refractories. Thus, the volume of flue gases entering the air-pollution-control devices is less for most slagging incinerators. If the flue gases are cooled to the same temperature level prior to entering the air-pollution-control equipment, the capacity (cost) of the control device will be proportional to the flue-gas volume; and thus, smaller and less costly air pollution control equipment will be required for total incineration systems.

However, in total incineration systems, a greater amount of heat must be removed in cooling the gases prior to particulate removal. A part of this heat load may be removed in a steam boiler, or it may be removed in a recuperator as preheat for combustion air, thereby reducing the supplementary heat and energy requirements for the process.

Elimination of Grates

Some of the systems do not require grates for supporting the refuse while it is burning. However, other components, such as the water-cooled monkey and monkey cooler, refractories, and water-cooled walls are exposed to high temperature fluxing and oxidation-corrosion, which may offset the advantages from elimination of grates.

Disadvantages

Air Pollution

The higher temperatures required for fusion of ash residue should result in substantially more nitrogen-oxide formation, as compared to normal incineration at about 1800°F. The equilibrium nitric oxide concentration for combustion gases with 10 percent excess air is about 200 ppm at 2000°F and 2000 ppm at 3000°F [9]. Although equilibrium concentrations would not be expected, the rate at which equilibrium is approached increases rapidly with temperature. The nitrogen oxides concentration in the flue gases from incineration seems to correlate with the heat-release rate as it does in the combustion of fossil fuels [1]. The higher heat-release rate is slagging incinerators leads to an expectation of higher rates of nitrogen oxides formation.

Other noncombustible gaseous pollutants from combustion of refuse constituents (e.g. SO₂, HCl) will be unchanged from the amounts generated in normal incineration operations at 1800°F. Particulate emissions and the efficiency of emission control necessary will vary with the design of the systems. Those systems characterized by high gas velocities may require more efficient particulate-removal devices to reach the same stack-emission level as conventional incinerators.

Auxiliary Heat Requirements

Supplementary heat required to maintain slagging temperatures will result in a significant additional cost of operation over conventional incineration costs.
Operational Complexity

The addition of ash fusion to the incineration process complicates the operation. If incineration and ash fusion are performed in the same unit, difficulties with ash fusion and slag tapping will affect the incineration portion of the process.

If the ash fusion is in a separate unit, both operations must be kept somewhat in phase to avoid overfeeding or starvation of the ash-fusion unit. In either case, the inclusion of ash fusion in the process will require increased attention of the operator.

Safety

The higher temperature ash-fusion operation and the handling of fused slag constitute increased hazards over conventional systems. However, handling of such materials is done safely on a routine basis in the metallurgical industries and on a much larger scale.

Problem Areas

Operating Labor

The relatively greater complexities of ash fusion processes may require greater operating skills as compared to conventional incineration, with the possible exception of the Sira process. Additional employee training can result in somewhat higher labor costs and should place increased emphasis on employee-retention efforts.

Design and Construction Materials

The higher temperatures and operational sensitivity of ash-fusion systems require a well-engineered, integrated design; special attention is required in the selection of the materials, process equipment, instrumentation, and maintenance to insure acceptable unit life and reliability. Thermal cycling resulting from shutdown of the equipment is expected to be more severe than in conventional systems.

Slag Fluidity

Difficulties may be encountered with low slag fluidity (high viscosity) and solidification due to either poor temperature control or variations in the noncombustible content of the refuse. Depending upon the chemical properties of the noncombustibles, varying amounts of limestone and other fluxing agents may be required.

AIR-POLLUTION CONTROL

Ash-fusion incinerators should require smaller particulate-control devices because of lower flue-gas volumes per ton of refuse, due to the low percent of excess air required. Particulate loadings and size distribution of particulate will depend upon the actual system design and operating practice.

For systems with higher temperature combustion gases and good mixing patterns, there will be a more complete burnout of combustible particulates. This together with probable fusion of the particulate may reduce the loading of the smaller particles which are more difficult to remove. The particulate contribution to the flue gases from entrainment of mineral ash prior to attainment of ash-fusion temperatures will vary with the system configuration and operating characteristics.

PROCESS ECONOMICS

Capital Investment Costs

The components of the slagging-incinerator systems that are common to conventional incinerator installations are as follows:

1. foundations and buildings with locker rooms, offices, maintenance shop, etc.,
2. refuse storage and handling equipment,
3. incineration furnace,
4. flue-gas conditioning or cooling,
5. air-pollution-control-system,
6. residue-handling equipment, and
7. induced-draft fan and stack.

The costs of the first two components are expected to be equivalent to those for conventional systems, comprising about 40 to 60 percent of the total capital investment. The costs for slagging system furnaces, the third item described, would reflect the necessity for operation at higher temperatures; however, the cost of a grate is eliminated, except in those systems where a slagging furnace is added on after conventional incineration. Thus, the cost of the furnace portion of the plant for most slagging systems would be expected to fall within a 20 percent range of the cost of conventional continuous-grate systems. In conventional plants, the furnace portion of the system comprises about 35 to 45 percent of the total capital investment.
The costs for flue-gas cooling, air-pollution-control devices, and the fan and stack (the fourth, fifth, and seventh components described) usually amount to about 10 to 20 percent of the capital investment for conventional systems, depending upon the type of flue-gas cooling, the type of air-pollution control, and the volume of flue gases per ton of refuse processed. If the flue gases are cooled with a recuperator or with a convection steam boiler, the cost increment will be increased, but the increase would apply equally to both conventional systems and to ash-fusion systems. However, if the same particulate loadings and removal efficiencies are specified, the savings in air-pollution-control equipment costs will be proportional to the 0.7 or 0.8 power of the flue gas volume ratios. A savings of about 5 percent of the total capital investment may thus be possible with ash-fusion incineration due to the lesser volume of flue gases.

Costs of residue handling equipment, the sixth component, generally comprise 5 to 10 percent of the total investment for conventional incinerators. The significantly lower ash volume from fusion incinerators could possibly halve the cost of this portion of the total system. If the slag is slow cooled in a dry-slag pit, residue-conveyor costs and maintenance costs associated with quench-water corrosion will be eliminated. Such savings could be offset to some extent by the added cost of power equipment for digging and loading the residue from the slag pit.

In summary, the capital costs for ash-fusion incinerator systems should not vary significantly beyond the normal spread in costs for conventional grate systems. It is possible that the potential savings in capital costs for residue-handling equipment, air-pollution-control equipment, fan, and stack would be offset by increased costs associated with the slagging aspects of the furnace.

Operating Costs

Operating costs for ash-fusion incinerators have been analyzed in a similar manner to that for capital costs discussed above. For the purposes of this discussion, operating costs include the following:

1. labor and supervision,
2. maintenance (labor and materials),
3. electric power and water (utilities),
4. auxiliary energy (coke, gas, electric power, and/or oxygen), and
5. materials (limestone, graphite electrodes, etc.).

The costs for labor and supervision are expected to show no significant differences as compared to continuous-grate systems, since the number of employees required to operate the plant should be about the same. Differences resulting from the reduced volume of residue to be handled should be offset by the additional handling of fuel and limestone. It is possible that maintenance costs might be increased with the higher operating temperatures required of ash-fusion systems. However, elimination of grate maintenance or a decrease in the size of grate required for the fusion process may compensate for possible higher refractory-maintenance costs. General plant utilities costs, including electric power and water, should also be the same order of magnitude as required for conventional systems.

Ash-fusion incineration processes require varying amounts of auxiliary fuel or energy in the form of coke, natural gas, electric power, and/or oxygen. Unless obtained by recuperation of waste heat by preheating the air for combustion, the cost of this extra energy is expected to add up to one or two dollars to the cost per ton of refuse processed; for the case of the oxygen-enrichment process, the additional cost may be greater depending on the size of the plant and the quantity of bulk oxygen required per day. Finally, the additional cost of materials, such as limestone and small quantities of other fluxing agents, will add a few cents to the operating cost over the conventional processes. In the electric-furnace process, there is the additional cost of graphite electrodes consumed, which might add about 40¢/ton of refuse to the cost of operation.

In the above comments, it has been assumed that there will be no credit for steam generation from waste heat, since the cost of the boiler and any electric-power generating equipment should be justified on its own merits, particularly since it applies equally to all types of incineration processes. Similarly, salvage of metals and glass, whether removed from the incoming refuse or whether removed from the ash residue, has been considered to have equal by-product value for all processes and, therefore, is eliminated from comparative evaluation. The most significant cost difference between the several ash fusion processes, therefore, is the additional cost of auxiliary fuel or energy.

SPECIFIC REQUIREMENTS
OF ASH-FUSION PROCESS

The DRAVO/FLK process may require some additional electric power because of a higher pressure
drop through the furnace. Also, additional power may be required for machinery to shred, feed, and provide distribution of refuse in the FLK furnace.

The American Thermogen process requires auxiliary fuel as either coke and/or natural gas, depending upon the design used. Because of the inherent high velocity of gases in the burning zone, it is expected that there will be a higher dust loading entering the air-pollution-control device; however, such dust-loading increase may be mostly due to large particles that can be removed easily; thus, the net effect on the cost of the air-pollution-control equipment may result in a negligible increase over other processes.

Since the Sira process requires preshredding of the refuse before incineration, there is additional cost over processes that accommodate refuse as received; however, this may be compensated for by lower building costs with outdoor-furnace construction. Anticipated higher dust loadings resulting from suspension burning may not represent increased costs of air-pollution equipment if the additional loading is mostly the result of larger particles.

The Ferro-Tech process utilizes a grate for a major portion of the incineration process. Therefore, there will be some added grate-maintenance cost. Also, there will be the added cost for supplementary coke fuel required to provide the high temperature necessary for fusion of the ash.

The Torrax process utilizes the heat energy from natural gas to preheat air for combustion in order to attain the high temperatures required for fusion of the ash. The probable higher pressure drop through this system should cause a slight increase in the electric power cost for gas-moving equipment.

The electric-furnace process utilizes a grate system similar to that required for the Ferro-Tech process and likewise will require some added grate-maintenance cost. The principal cost of the electric-furnace process is reflected in the power requirement of the three-phase electric-arc furnace. Also, there will be the cost of electrode consumption. Compensating these costs is the virtual elimination of flue gases from the electric-furnace melting process, thus reducing the capital and operating costs of air-pollution-control equipment and avoiding the formation of nitrogen oxides.

In the oxygen-enrichment process, the high temperatures necessary for residue fusions are attained by use of oxygen to enrich the air for combustion. Thereby, refuse-combustion energy is "concentrated" in a smaller flue-gas weight and higher flame temperatures result. Although use of enriched air gives a reduction in the volume of the flue gases, this savings may be offset by the particulate carry-over with the high velocity gases and in the additional energy cost from the higher pressure drop in the system. However, the cost of bulk oxygen is the major factor in the higher operating cost compared to other processes. Without heat recuperation, the oxygen required is about 0.3 to 0.4 ton/ton of refuse, depending on moisture content.

All of the ash-fusion processes require limestone and such other additional fluxes as needed to satisfy the ash composition resulting from the refuse processed; therefore, the cost of limestone and other fluxing agents may be considered equal for all fusion processes. Similarly, the added cost from a more complicated process than conventional incineration and from higher degrees of sensitivity are all approximately the same for the slagging units. Credits from the sale of granular slag or rock-like high-strength slag and from possible salvage of fused metal have been considered to be equal and are cost trade-offs for the various ash-fusion processes.

**CONCLUSIONS**

It is believed to be technically feasible to produce fused slag instead of "bonfire ash" by total incineration of industrial and/or municipal refuse.

The fused-slag residue represents the lowest possible volume of ash residue from refuse. The added capital and operating costs for producing fused-slag residue over the cost of producing a nonfused ash residue from conventional incineration must be demonstrated in any of several proposed total incineration systems; the additional cost may be small, depending upon the system used.

Air pollution from total incineration systems can be controlled with conventional air-pollution-control devices. Costs for such air-pollution-control systems are uncertain inasmuch as total incineration systems may produce higher particulate loadings (higher efficiency required) but lower flue-gas volume flows than conventional incineration.

The operation of total incineration systems will require new and additional skills of plant-operating personnel.

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REFERENCES


