INTRODUCTION

The thought of burning run-of-the-mine coal in a 1000-Mw utility power plant is appalling. The results would be catastrophic. The furnace would have to be oversized; the unburned combustible loss would be high; the excess air required would be great, thus increasing the amount of flue gas to be cleaned; control of furnace conditions would be next to impossible; stack emissions would be excessive; etc. For these reasons, coal is washed, sized, crushed, and pulverized to 65 to 75 percent less than 200 mesh, pneumatically transported to the furnace, and burned in suspension. These methods of preparation and handling are known and accepted as being necessary. Why then do we think we can do a good job of burning an inferior fuel such as refuse in the raw state? When tried, we experience each and every problem that has been overcome in the burning of other hydrocarbons such as coal, oil, gas, bark, and bagasse.

Historically, it has been the desire to reclaim more heat from waste fuels at less cost that has led to improved methods of preparing, conveying, and burning. This was true with bark, bagasse, blast furnace gas, pitch, etc. It was a long and costly process, but the industries that produce these wastes finally developed economic means of disposing of them while reclaiming their heat content. Considering that approximately 400 billion pounds of refuse will be produced in the United States next year, we cannot wait for the normal process of developing improved methods of preparing, conveying, and burning this waste material. Improvements must be initiated now.

It is within the limits of our present technology to treat the preparation, conveying, and burning of refuse in a manner similar to coal or other fuels. The more homogeneous wastes such as bark and bagasse have, for years, gone through size-reduction processes, have been conveyed pneumatically in pipelines for great distances, in some cases across international borders, and recently have been burned in suspension. However, some engineers may not realize several important facts. First, there is on the market today equipment capable of size reduction, pneumatic conveying, and suspension burning of industrial and municipal refuse. Secondly, refuse shredding and

<table>
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<th>Value</th>
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<tr>
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<tr>
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<td>H₂O</td>
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<tr>
<td>Inert</td>
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<tr>
<td>HHV</td>
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Table 1
Typical Municipal Refuse
size reduction have been practiced for years, as have pneumatic conveying and suspension burning of certain types of industrial refuse. Finally, good results have been realized when testing this equipment with municipal refuse. The tests were run with refuse that varied from steel pipe and rocks to paper.

Three systems for pneumatic conveying and suspension burning of prepared refuse are described later in this paper. These systems are either under construction or proposed. Unless otherwise noted, the basis for the predictions given is a typical mixed municipal refuse as described in Table 1.

REFUSE PREPARATION AND CONVEYANCE

Based on tests and experience with hogged bark and bagasse, it was determined that the refuse should be reduced to a maximum size of 2 in. x 2 in. before being conveyed. This can be accomplished in a one- or two-stage machine. The power consumption will be approximately 15 to 20 kWh per ton of refuse processed, and capital costs will be approximately $150 to $200 per ton of daily capacity. Through refuse preparation, magnetic and ballistic separation of saleable scrap metal is simplified.

The prepared refuse is collected in a cyclone, which separates the refuse from the air that carries it from the shredder discharge. The refuse may now follow one of two possible paths. It can be delivered to a high-pressure pneumatic system for conveying directly to the furnace. Or, it can be delivered to a storage silo from which it would be fed at a predetermined rate to the high-pressure pneumatic system for conveying to the furnace. If storage is nearby, the refuse can be conveyed to storage via belts, pneumatic conveyors, etc. Usually refuse is conveyed to storage pneumatically if storage is a considerable distance away, for example, if the refuse is delivered to a shredder located near Broadway and 42nd Street in New York City and must be delivered to an incinerator located on the East River, on Staten Island, or in New Jersey.

The ability to move refuse in this manner suggests many approaches to reducing transportation costs that consume a great part of the refuse disposal dollar.

SUSPENSION BURNING

Shredding the refuse so that it will pass a 2-in. square mesh or smaller is a prerequisite not only for
pneumatic conveying but also for suspension burning. A suggested burning system is the one used in the three units described later in the paper. It is termed "tangential firing." The term "tangential" derives from the method used to introduce the fuel into the furnace, in this case refuse and combustion air.

Four pneumatic lines deliver refuse to each elevation of tangential nozzles, one line per corner. The refuse and the heated combustion air are directed tangentially to an imaginary cylinder in the center of the furnace (see Fig. 1). Fuel and air are mixed in a single fireball. This procedure precludes the possibility of poor distribution of fuel and air; it also permits operation with less excess air, thereby reducing the size of the flue gas cleaning equipment. The refuse nozzles can be tilted upward or downward to accommodate variations in refuse characteristics and load. With tangential firing, the fuel particles have a longer residence time in the hottest furnace zone, thereby assuring complete combustion of waste fuels with low heat content.

As the burning refuse particles spin downward, additional preheated combustion air is introduced in the lower furnace through multiple rows of tangential nozzles. This continues the combustion process and maintains particle momentum. Since the larger refuse particles will not be completely burned in suspension, a small grate may be required in the bottom of the furnace to complete combustion of the larger particles and to remove ash.

Oil or gas firing is usually included for use during startup and as a secondary fuel.

**INCINERATOR BOILER**

When there is an in-plant demand or a nearby market for steam or electricity, it is usually a simple matter to justify the cost of installing a boiler system to reclaim the heat generated from refuse incineration (1). Even when there is no immediate use for the steam other than for the boiler auxiliaries, it may be possible to justify a boiler when one considers the savings in the cost of flue-gas cleaning that results from lower excess air in the furnace and elimination of spray-water cooling of the flue gas. The heat in the unused steam would be dissipated in air- or water-cooled condensers. Fig. 2 illustrates the potential for steam generation from refuse and the effect a boiler has on the volume of flue gas to be cleaned.

There are two boiler design problems that must be given special consideration when firing refuse. These problems are fouling of heating surfaces and potential corrosion. It is imperative that the boiler designer treat these problems correctly in order to insure a high availability factor for the refuse disposal unit.

In a refuse-fired boiler, all sections of the heating surface (waterwall, superheater, generating bank, economizer, and air-heater tubes) are subject...
to fouling from slag and fly-ash deposition. Proper furnace sizing, arrangement of heating surfaces, and correct use of soot blowers can reduce fouling to an acceptable level.

Proper furnace sizing means providing adequate volume and residence time to insure complete burnout. The required volume and dimensions for flame travel will vary with the method of fuel preparation, burning mechanism (i.e., fixed grate, reciprocating grate, traveling grate, suspension firing, etc.), overfire air and underfire air system, and the amount of water cooling in the furnace. Proper furnace sizing also means providing sufficient water cooling to reduce the temperature of the products of combustion to the point where the ash is not fluid and thus will not "freeze" on boiler tubes. This type of deposit is difficult to remove with soot blowers. Also, the furnace design must provide for a temperature in the burning zone that is high enough to destroy bacteria.

The next step in preventing serious slag and fly-ash deposition is proper arrangement of the heating surface. This begins with adequate furnace cooling of the flue gas and is followed by using wide convection tube spacing, especially in the high-gas-temperature zones, and in-line tube rows. Staggered tube rows should not be used in a refuse-fired unit. Also, the gas velocity should be low, and retractable soot blowers should be used to clean the convection heating surface.

The second problem mentioned previously is that of potential corrosion. When a high percentage of the boiler heat input is from refuse, the problem can be a serious one; inattention to it or being overly optimistic during the design stages can result in extremely high maintenance costs and greatly reduced incinerator availability. There are at least four recognized types of corrosion that must be considered by the designer. These are (1) high-temperature, liquid-phase corrosion, (2) corrosion due to non-uniform furnace atmosphere, (3) corrosion by HCl, and (4) low-temperature or dew-point corrosion. A brief discussion of each follows.

High-temperature, liquid-phase corrosion is probably caused by molten alkali-metal sulfates. Much has been written about this type of corrosion, and some disagreement seems to exist among investigators on the exact corrosion mechanism and the temperature range in which it occurs. However, it is generally agreed that this type of corrosion is likely to occur at metal temperatures above 900°F. Recent data indicate that high gas temperatures aggravate the problem. One obvious way to avoid high-temperature corrosion is to eliminate high metal temperatures that occur in superheaters of units where refuse contributes a high percentage of the heat input.

The second type of corrosion is caused by the products of partial combustion in a reducing atmosphere. A reducing atmosphere can be present locally in a unit supplied with 200 percent or more excess air as a result of stratification or improper air or fuel distribution. Thus, carbon monoxide or hydrogen sulfide can be produced. It is thought that these compounds attack and cause failure of water-wall tubes by reducing the iron oxide on the surface of the tubes. It is important, therefore, that the burning system provide not only the correct fuel-air ratio but also proper distribution of air to the fuel and sufficient turbulence to prevent stratification. The tangential burning system described above should accomplish this.

The third type of corrosion, resulting from HCl and Cl, has been recognized for years. Chlorine is introduced in the form of polyvinyl chlorides in plastics. There is also much disagreement on the mechanism and temperature range of this type of corrosion. It is the author's opinion that metals operating at temperatures above the dew point and below 550°F should not suffer severely from HCl and Cl attack.

Finally, low-temperature or dew-point corrosion occurs when the flue gas contacts surfaces that are at temperatures below the dew point of corrosive
constituents in the gas. Temperatures low enough to cause acid condensation may be found at the water-inlet end of an economizer if the feedwater temperature is too low, in the cold end of an air heater, and on boiler outer casings. For this reason, welded-wall construction such as that shown in Fig. 3 is considered desirable. The tubes and fins are welded to form a self-cased, pressure-tight envelope to prevent flue gas from contacting a cold casing. Low-temperature corrosion could also be a problem during unit outages. Some deposits are corrosive; and, where the deposits are hygroscopic, the problem becomes more severe as the length of the outage increases. If a lengthy shutdown is contemplated, the fireside of the unit should be water washed, or, alternately, the unit could be kept hot by using an external source of heat.

SYSTEMS FOR GENERATING STEAM FROM PREPARED REFUSE

Refuse-Fired Unit, Saturated Steam

This is the simplest of the three systems under discussion. Steam is generated at 400 lb/\text{in}^2/\text{g} saturated; there is no superheater. The analysis of the refuse to be fired is listed in Table 2. The system is shown schematically in Fig. 4 and to scale in Fig. 5. The refuse throughput is 180 tons per day (15,000 lb/h), and sludge is dried and incinerated at the rate of 114 tons per day (9500 lb/h). The resulting steamflow is 77,000 lb/h at 400 lb/\text{in}^2/\text{g}.

![Table 2](image_url)

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<td>HHV</td>
<td>7,300 Btu/lb</td>
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The refuse is shredded and conveyed pneumatically to storage. From storage, it is metered to a vibrating distributor, which feeds the shredded refuse to four pneumatic transport systems for delivery to the four corners of the furnace. Here it is injected through the tangential nozzles and burned in suspension, except for the larger particles, which will complete burning on a four-section, dump-type grate.

The influence on design of the two potential boiler problems described previously, those of fouled heating surfaces and corrosion, is evident throughout the boiler. The furnace is equipped with provisions for the future installation of wall deslagers similar to those used in furnaces firing pulverized coal. The deslagers can be easily installed should slag buildup on waterwalls become a problem.

An area where slagging is more likely to be a problem is the boiler convection bank. However, the furnace was sized generously to reduce the exit gas temperature to approximately 1550°F. A single-pass design was used, and the average gas velocity is 20 ft/sec. The boiler tubes are in-line, and the clear space between adjacent rows is 4 in. This combination of low gas temperature, low gas velocity, in-line tubes, and wide tube spacing will minimize slag deposition. Retractable soot blowers are installed to remove any deposits that may accumulate. The economizer is designed with in-line tubes that have no fins or extended surfaces. Wide spacing (2-in. o.d. tubes on 4-in. centers) and low gas velocities (30 to 35 ft/sec) are used to minimize ash buildup and erosion. A shot cleaning system will be used to clean the economizer and the tubular air heater.

The second potential problem, that of corrosion, should not be serious in this unit. Without a superheater, the potential for high-temperature corrosion is greatly reduced. The tangential burning system should provide proper mixing of fuel and air and will produce a far more uniform furnace atmosphere than a unit fired with unprepared refuse on a stoker. Therefore, we do not expect serious corrosion from sulfides or CO. Dew-point corrosion will not occur on the outer casing due to the use of welded walls and should not be a serious problem in the air heater due to the high gas-exit temperature (550°F) at full load and the use of a steam air preheater at low loads.

An interesting feature is the sewage-sludge flash-drying system for disposal of 114 tons of sludge per day. Hot flue gas is taken from between the boiler convection bank outlet and the economizer inlet at 950 to 1000°F and routed to the flash drier where it
is used to reduce the moisture content of the sludge from 80 to 15 percent. The dried sludge and cooled gas at approximately 300°F are separated in a cyclone. The dried sludge is conveyed pneumatically to the furnace for suspension burning, and the cooled gas is ducted to the furnace where it will be deodorized. All sludge ash is removed with the refuse ash. The flash-drying system was incorporated into the incinerator-boiler system because it provided deodorization, ash disposal, and air-pollution control at lower first cost and lower operating costs.

Refuse and Oil-Fired Unit, Superheated Steam

The refuse-burning capacity of this system is 300 t/day.
The desired steamflow at the superheater outlet is 300,000 lb/h at 650 lb/in²/g and 825°F. There is enough heat available in the refuse to generate approximately one-third of the steam flow; the remainder will be produced from firing oil. An additional requirement is that the system be capable of producing 300,000 lb/h steamflow when firing oil only.

As shown in the schematic flow diagram (Fig. 6), the system consists of two boilers, one refuse-fired unit to generate one-third of the steam, and one oil-fired unit to generate two-thirds and to superheat all of the steam. It would be possible to combine these two functions in a single unit; however, the superheater would then be subjected to temperatures in the high-temperature corrosion region. Since an extremely high availability of steamflow is a plant requirement and there is no standby incinerator, it was deemed prudent to isolate the refuse-fired unit.

The refuse-fired boiler is very similar to the 180-ton per day unit described above. It is physically larger because of the higher refuse-burning capacity, and there is no sludge-disposal system. However, all the steps employed to minimize corrosion and fouled heating surfaces are present, and the unit should have a high availability factor. The refuse shredding, conveying, and burning systems are the same except for capacity.

Oil is fired in the conventional unit equipped with a two-stage superheater. It is obvious that a superheater designed to produce an 825°F outlet temperature when firing oil to generate two-thirds of the steamflow will have a considerably higher outlet temperature when the oil-fired capacity is increased to 100 percent of the steamflow. For this reason, a stray-type desuperheater is installed between the first and second stages of the superheater to limit the final steam temperature to the design value when more than two-thirds of the steamflow is being generated from oil firing. Such an arrangement works well for this ratio of refuse-generated steam to total steamflow and an 825°F outlet temperature. There are some ratios and outlet temperatures that may impose a limit on the oil-firing rate when the refuse-fired unit is not delivering steam to the superheater. However, this would occur only with very high design steam temperatures or when the refuse produces the major portion of the steam flow.

**Coal-Fired Utility Boiler**

The third system uses a coal-fired utility boiler adapted to burn 10 percent refuse. The unit discussed is a 125-MW, pulverized-coal-fired central station utility boiler. The refuse-firing rate is approximately 10 percent of the total heat input to the unit or approximately 250 tons per day of 6000 Btu per lb of refuse. The refuse will pass through shredding and magnetic plus ballistic separating equipment. It will then be conveyed pneumatically to the tangential firing system for suspension burning along with pulverized coal.

The advantages of this system are a reduction in the cost of refuse disposal and a saving in fossil-fuel cost. Use is made of the existing burners, furnace and boiler, fans, air-pollution control devices, and ash-removal equipment. Additional savings are realized through the use of existing plant facilities such as laboratories, offices, security, parking, etc.

The effects of burning 10 percent refuse should be very slight, if not negligible, in the existing equipment. No significant increase in slagging or corrosion is anticipated; there may even be a minor reduction in the potential for low-temperature corrosion due to the reduced sulfur input. Comprehensive tests will determine the exact effects.

**CONCLUSION**

With today's technology, we are capable of improving our methods of conveying and burning refuse in order to have better burnout, reduce stack emission, and reduce the cost of refuse conveying, residue removal, and flue-gas cleaning. Work is presently being done to implement these improvements. It is logical that we also take steps to improve our methods or reclaiming the heat liberated from refuse incineration. However, there are some obstacles to be overcome. These obstacles and some proposed solutions are described in this paper, and it is the author's belief that these proposed solutions will help us realize the goal of reliable equipment for recovering heat from refuse incineration.

**REFERENCES**
