ASH MANAGEMENT CONSIDERATIONS FOR REFUSE-FIRED BOILERS

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ABSTRACT

This paper addresses ash management considerations that apply to the burning of municipal solid waste (MSW). These considerations include ash characteristics, ash distribution, problems with the ash, ash conveying methods, ash system efficiency and ash system economics. The authors stress the importance of safety and reliability while emphasizing that careful planning and sound engineering are prerequisites for the successful design of a total system for conveying ash from a refuse-fired boiler.

INTRODUCTION

The use of Refuse Derived Fuel (RDF) as a fuel for steam generating boilers is gaining momentum. The ash which results from the firing of RDF imposes a set of design conditions distinct from those associated with the handling of traditional coal ash.

CHARACTERISTICS OF REFUSE AND ASH

Municipal solid waste is a heterogeneous substance consisting of a variety of materials. Its inherent characteristics distinguish MSW from conventional coals and other solid fuels; for instance, the moisture content of refuse can be three times that of coal, while the corresponding higher heating value for either prepared or unprepared refuse is less than half that of coal. The as-fired sulfur content of refuse is low, as with many non-fossil fuels, but the chlorine content of refuse is considerably higher than that normally found in coal. An overall assessment of the fuel properties critical to this discussion reveals that, except for the sulfur content, refuse contains more potentially detrimental properties than coal. The characteristics shown in Table 1 are indicative of typical refuse values.

The MSW combustion process produces 1.5 to 2.5 times the quantity of ash produced by the burning of coal using the as-received weight of fuel as the basis for comparison. An analysis shows wide diversity in the elements which constitute this ash. The range of values for certain refuse fly ash components (such as oxides of aluminum, iron, sulfur, calcium and silicon) may be twice as broad as compared with coal fly ash [1]. Due to this extreme variability in ash constituents, ash collection systems for refuse-fired boilers should be conservatively designed.

Hygroscopicity, the ability to absorb moisture from air is a potential problem for refuse fly ash. If the combined percentage of calcium oxide (lime) and magnesium oxide (magnesia) in the ash analysis exceed 15 percent, the possibility exists that moisture will react with the CaO/MgO and form compounds possessing cementitious properties [2]. These compounds usually are incapable of being re-dissolved and flushed out of tanks or conveying lines. Fly ash allowed to remain in collection hoppers may absorb moisture from the flue gas and agglomerate while awaiting removal. It is recommended that fly ash not be stored in hoppers or intermediate collection tanks and its contact with water should be minimized.

REFUSE FIRING TECHNIQUES AFFECT ASH DISTRIBUTION

Fuel can be delivered to the steam generator furnace in either an “unprepared” form, i.e., refuse as received,
FIG. 1 MECHANICAL BOTTOM ASH SYSTEM
with very little or no preparation of any kind, or a "prepared" form, i.e., refuse processed to have a semi-uniform consistency, usually with a percentage of the metal and glass recovered. The method for burning unprepared refuse uses a moving, tumbling grate and is called "mass burning." The method for burning prepared refuse utilizing pneumatic or mechanical distributors which spread refuse derived fuel over a grate surface is called "spreader-stoker firing." Prepared refuse can also be burned in furnaces utilizing standard fuel windboxes; this method is called "full suspension firing".

Since the refuse size is not reduced before entering the furnace, the bulk of combustion in mass burning occurs on the stoker grate surface. This firing method produces a higher percentage of bottom ash than fly ash. In comparison, spreader-stoker firing burns prepared refuse using a semi-suspension system; the lighter fraction of the fuel burns in suspension above the stoker, and the heavier portion burns on the stoker grate. A higher percentage of fly ash than bottom ash is produced. Full suspension firing is used for firing of refuse as a supplementary fuel in a coal burning furnace. Since the emphasis of this paper is on resource recovery plants burning refuse exclusively, full suspension firing will not be discussed.

Table 2 shows the "actual" bottom ash and fly ash breakdown percentages that result if the total amount of ash is equal to the theoretical quantity obtained by multiplying maximum percent ash by the maximum fuel fired. However, due to the variability of the fuel, the prudent system designer should increase the bottom ash and fly ash percentages so that the total "design" ash quantity will be 20 percent to 40 percent in excess of the theoretical ash quantities.

Another ash management consideration is the size distribution expected in the bottom ash and the fly ash. Tables 3 and 4 show that the method of firing the fuel has substantial impact on the size distribution.

**PROBLEMS WITH MSW ASH**

The burning of MSW produces ash which has a high carbon content and is very corrosive. Problems with conveying and storing this ash are attributable to these two characteristics.

**CARBON CONTENT**

The percentage of carbon in the refuse is approximately one-third that found in coal (Table 1). The carbon loss or amount of potentially combustible material carried over in the flue gas can be as much as sixteen times higher for refuse firing than for coal firing. This increased loss is detrimental for the following reasons:

(a) fuel which could be burned is being "lost out the stack," decreasing the boiler efficiency as a result of incomplete combustion;
(b) the quantity of fly ash is increased, requiring higher ash conveying rates and larger particulate removal systems;
(c) as ash conveying rates increase, wear on components intensifies. Additional maintenance costs are the results;
(d) a high potential exists for fires in fly ash collection hoppers because of a high fraction of combustible material.

A reinjection system which pneumatically transports carbon back into the furnace in an attempt to improve the boiler efficiency has been used in numerous instances. This approach has had limited success. With all indications that carbon loss is and will continue to be a real problem in the burning of MSW, fly ash conveying systems must be designed accordingly. In order that the system is not undersized, all heat and mass balances for the boiler must take into account the 3 percent to 4 percent carbon loss value shown in Table 1. The use of the 130 percent value shown in Table 2 is highly recommended as a minimum design number.

Safety-related problems associated with refuse-derived ash deal mainly with its ability to sustain fires and its tendency to cause explosions. Bottom ash can be considered relatively inert. No danger from fire or explosion exists once the residue is deposited into the quenching bath of the bottom ash conveying system.

Fly ash, however, is an entirely different matter. Due to its high carbon content, conveying of refuse fly ash can involve situations which are potentially hazardous to equipment and personnel. Flue gas carries with it quantities of unburned and burning particulate matter. If ash is stored in collection hoppers, then incoming burning particles may ignite those particles not yet burned. A fire in an ash hopper is not a desirable condition for either the integrity of the hopper or the ash conveying equipment which the hopper is feeding.

If a pneumatic vacuum system is used to convey fly ash, the separating equipment on top of the silo presents additional problems. The ash-laden conveying medium must pass through a cyclone separator and a bag filter. The concern with the cyclone is that it will separate the largest pieces, which may be smoldering, and dump them into the silo. Silo conflagrations are testimony to the fact that smoldering pieces of fly ash can ignite other particles of unburned carbon.

Located downstream of the cyclone, the bag filter will receive the remaining particulate matter. Burning particles can make holes in the filter material and set the bag
# TABLE 1 FUEL ANALYSIS, TYPICAL VALUES [3]

<table>
<thead>
<tr>
<th></th>
<th>Unprepared Refuse</th>
<th>Prepared Refuse</th>
<th>Bituminous Coal (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Higher Heating Value,</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>As-Fired; BTU per Pound</td>
<td>4600 (2560)</td>
<td>5690 (3160)</td>
<td>13390 (7440)</td>
</tr>
<tr>
<td>(KCAL per KG)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Carbon, % (2)</strong></td>
<td>28.6</td>
<td>35.3</td>
<td>74.6</td>
</tr>
<tr>
<td><strong>Moisture, % (2)</strong></td>
<td>28.8</td>
<td>25.9</td>
<td>8.6</td>
</tr>
<tr>
<td><strong>Ash, % (2)</strong></td>
<td>21.8</td>
<td>13.0</td>
<td>8.4</td>
</tr>
<tr>
<td><strong>Sulfur, % (2)</strong></td>
<td>.10</td>
<td>.12</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Chlorine, % (2)</strong></td>
<td>.30</td>
<td>.20</td>
<td>.10</td>
</tr>
<tr>
<td><strong>Carbon Loss, % (3)</strong></td>
<td>4.0</td>
<td>3.0</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Pounds of Ash Per</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Million BTU</td>
<td>47 (85)</td>
<td>23 (41)</td>
<td>6 (11)</td>
</tr>
<tr>
<td>(KG per million KCAL)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

(1) - For comparison, coal shown is Illinois, high-volatile B.
(2) - Constituents are listed as percent by weight in fuel, as-received.
(3) - Carbon loss is not a fuel property. It is dependent strictly on the method of fuel firing. Percentages indicate loss in combustion heat balance by ASME short form.
filter on fire, severely reducing its efficiency and permitting a large amount of carryover to enter the vacuum producer. If the magnitude of ash carryover becomes excessive, the vacuum producer will be rendered useless.

Fires are sustained by the combination of air, fuel and ignition. If a fourth prerequisite, confinement, is present, a fire can quickly evolve into an explosion. The dramatic rise in confined internal pressure can cause catastrophic bursting of a vessel's walls. Experts indicate that the majority of all industrial explosions occur during startup, shutdown or upset conditions [8]. Designing an ash conveying and storage system to minimize the possibility of explosions is always essential.

CORROSION

Corrosion is much more severe in a refuse-fired furnace than in a coal-fired furnace mainly due to the presence of
aluminum, rubber and plastic. Chlorides, which are released during the combustion of polyvinylchloride (PVC) plastics, are especially troublesome because these compounds form acidic condensates in the flue gas. The fly ash conveying system, portions of which operate in the temperature region below the acid dewpoint, is susceptible to metal attack by acidic condensation. As it is impractical to maintain the temperature of the ash system above the acid dewpoint, approximately 240 to 340°F (116 to 171°C) [9], the effects of corrosion can be lessened by the introduction of flue gas instead of air into the pneumatic pipeline.

Flue gas for this application can be extracted from the precipitator outlet duct and can be piped to the conveying line inlet. Even though flue gas is corrosive while air is not, the use of flue gas with its elevated temperature in lieu of air at ambient temperature keeps the conveying process temperature closer to the acid dewpoint and lessens the effects of corrosion. If heat tracing and insulation are also added to the conveying pipeline, the formation of condensates is even less likely.

If quenching water is used in the hydraulic process of conveying bottom ash, this water must be treated for variations in its pH. Due to diverse ash characteristics, the pH control system should be capable of correcting both acidic and alkaline conditions, even though the condition of excess acidity is the main cause of concern.

The ash system designer must realize that ash derived from MSW is dissimilar to ash produced by the burning of fossil fuels. Recognition of these differences in the design stage will greatly add to the reliability and availability of the ash conveying system.

ASH CONVEYING METHODS

The three principal methods of transporting ash from the collection points to the disposal or storage location are (a) mechanical, (b) hydraulic, and (c) pneumatic. Mechanical transport embodies the philosophy of continuous ash removal, while hydraulic transport and pneumatic transport comprise that of intermittent ash removal. In addition to the three methods of conveying, ash system designers can utilize separate bottom ash and fly ash systems, or they may elect to have all of the ash conveyed by a single combined system.

BOTTOM ASH SYSTEMS

Mechanical

Mechanical transport of bottom ash utilizes an above-grade Submerged Scraper Conveyor (SSC) which quenches and dewateres the ash as the ash discharges from the stoker grate. The siftings collected under the grate are transported via a screw conveyor to the SSC for quenching. Using flight or belt conveyors, the combined product is then moved to the disposal site or the truck loading station. The system is designed to run continuously (Fig. 1).

Hydraulic

Hydraulic transport of bottom ash employs a water-impounded storage hopper discharging through a sluice pipeline by means of slurry or jet pumps. The slurry flows to a pond for final disposal or to dewatering tanks where the material is transferred to trucks. Due to the storage hopper's configuration, it is impractical to deposit siftings into the hopper. Instead, they enter the conveying line at a point outside of the hopper. The system runs intermittently; ash is stored in the hopper for up to eight hours before evacuation (Fig. 2).

Pneumatic

Pneumatic transport of bottom ash makes use of a dry ash storage hopper providing no water impoundment. The hopper contents discharge into clinker grinders which reduce clinkers to a size that can be handled by a pneumatic vacuum conveying system. The ash is transported to a silo for intermediate storage. Siftings, considered as a branch line of the pneumatic system, are conveyed in an identical manner. This conveying system also runs intermittently; ash is stored in the hopper for up to 8 hr awaiting removal (Fig. 3).

Table 5 indicates the various bottom ash system possibilities, along with comments on their suitability. Note that a pneumatic bottom ash system will nearly always be joined with a pneumatic fly ash system to produce a single combined pneumatic ash system.

FLY ASH SYSTEMS

The three primary methods of conveying fly ash from the collection hoppers to the storage location are (a) mechanical, (b) pneumatic, and (c) mechanical-pneumatic combination. It is essential to distinguish the concept of hopper evacuation from ash transportation, as this forms the basis for differentiating the three systems (Table 6).

Mechanical

A mechanical fly ash system employs conveyors which continuously transport the ash from collection points to the storage location. As fly ash is removed from the flue gas, it passes through the ash hopper and is immediately
FIG. 3 PNEUMATIC BOTTOM ASH SYSTEM
TABLE 2 ASH BREAKDOWN, ACTUAL AND DESIGN, TYPICAL VALUES

<table>
<thead>
<tr>
<th></th>
<th>Bottom Ash</th>
<th>Flyash</th>
<th>Total Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Burning - Actual Breakdown</td>
<td>60%</td>
<td>40%</td>
<td>100%</td>
</tr>
<tr>
<td>Spreader-Stoker Firing - Actual Breakdown</td>
<td>40%</td>
<td>60%</td>
<td>100%</td>
</tr>
<tr>
<td>Mass Burning - Design Breakdown</td>
<td>70%</td>
<td>60%</td>
<td>130%</td>
</tr>
<tr>
<td>Spreader-Stoker Firing - Design Breakdown</td>
<td>60%</td>
<td>70%</td>
<td>130%</td>
</tr>
</tbody>
</table>

TABLE 3 BOTTOM ASH, TYPICAL VALUES [4, 5]

<table>
<thead>
<tr>
<th>Size Distribution, % By Weight</th>
<th>Density Lb/ft³ (Kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.25 Inch (&lt;6.3 mm)</td>
<td></td>
</tr>
<tr>
<td>&lt;1.5 Inch (&lt;38 mm)</td>
<td></td>
</tr>
<tr>
<td>&lt;5 Inch (&lt;127 mm)</td>
<td></td>
</tr>
<tr>
<td>Mass Burning (1)</td>
<td>20% 50% 90% 60</td>
</tr>
<tr>
<td>(960)</td>
<td>(960)</td>
</tr>
<tr>
<td>Spreader-Stoker Firing</td>
<td>50% 98% 100% 45</td>
</tr>
<tr>
<td>(720)</td>
<td>(720)</td>
</tr>
</tbody>
</table>

Notes: (1) Bottom ash from mass burning is also called "residue" because of the large quantity of noncombustibles present with the ash.

deposited into the first of a series of conveyors. As installed on a precipitator, these initial conveyors can collect either parallel or perpendicular to the fields. The parallel arrangement with a single conveyor responsible for servicing a single field assures greater precipitator availability. See Fig. 4 for a typical mechanical conveying arrangement.

Rotary airlock valves have traditionally been utilized at each hopper outlet to isolate the flue gas particulate removal equipment from the ash system. Recent practice has been to eliminate the rotary valves and provide gas-tight conveyors which are attached to the maintenance gates which are, in turn, bolted to the hopper outlet flanges. Installed at the discharge of the conveyor is a double-dump valve which provides the required isolation. The conveyor becomes, in effect, an extension of the ash hoppers with flue gas free to circulate between the hoppers and the conveyor. One double-dump valve, located at the conveyor transfer point, has been exchanged for two to eight high-maintenance rotary valves.

There are various types of mechanical conveyors available. Mechanical flight conveyors are generally described as totally enclosed, noncarrying suspended flight conveyors. They have the return run above or below the carrying run, with the conveying elements confined in a totally enclosed casing to minimize the possibility of air infiltration. The flights are not in contact with the bottom of the trough, which eliminates wear on the trough floor.
TABLE 4 FLY ASH, TYPICAL VALUES (1) [6, 7]

<table>
<thead>
<tr>
<th>Size Distribution, % By Weight (2)</th>
<th>Density Lb/ Ft³ (KG/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10 Microns</td>
<td>&lt;20 Microns</td>
</tr>
<tr>
<td>Mass Burning</td>
<td></td>
</tr>
<tr>
<td>&lt;20 Microns</td>
<td>20%</td>
</tr>
<tr>
<td>&lt;30 Microns</td>
<td>35%</td>
</tr>
<tr>
<td>Spreader-Stoker Firing</td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>60%</td>
</tr>
</tbody>
</table>

Notes: (1) Average of economizer, air heater and precipitator/baghouse fly ash.

(2) Distribution by BAHCO device using assumed specific gravity of 2.5.

and reduces the noise level. These types of conveyors have been successfully used in the United States but are more widely used in Europe.

Another type of mechanical conveyor is the screw conveyor. To ensure the integrity of the screw conveyor for the abrasive duty of transporting fly ash, the screw flight should be hard-surfaced a minimum of 1.5 in. (38 mm) from the outer edge with Stellite or equal. As far as intermediate shaft bearings are concerned, the most successful installation will eliminate all internal bearings by restricting the overall length of the conveyors and by optimizing the locations of the conveyors in the plant. As with flight conveyors, screw conveyors have totally enclosed casings. Screw conveyors have been specified and purchased for both economizer and fly ash removal.

The last type of mechanical conveyor available is a belt conveyor. It is seldom appropriate for fly ash service since the temperature of the ash usually exceeds the temperature limit for the belt material. Belts, however, can be used for conveying dewatered ash from the Submerged Scraper Conveyor to a storage vessel.

Pneumatic

A pneumatic fly ash system uses mechanical blowers, water exhausters or steam exhausters to create a vacuum which removes the fly ash from the hoppers. A fly ash intake valve located below each hopper regulates the flow of ash into the vacuum line. Because the system operates on a vacuum, only one fly ash intake and one conveyor branch line operate at any given time. As each hopper is emptied of fly ash, the system will step to the next hopper in the same branch line. When all hoppers in a branch line have been emptied, the system will step to the next branch line. This method requires that ash be stored in the hopper while waiting for removal. This waiting period can be as much as 8 hr in a typical system although some systems run continuously, thereby minimizing the amount of time the ash remains in the hoppers.

Cyclone separators and bag filters are used to separate the fly ash from the conveying medium. Sophisticated dual-stage separators which require fluidizing air in their storage compartments are not recommended. It is advisable to add air to a situation where the conditions of fuel, ignition and confinement may already exist. The ash collected in the separating equipment is discharged to the silo interior (Fig. 5).

Mechanical-Pneumatic

A mechanical-pneumatic fly ash system combines operating philosophies of both the preceding systems. Mechanical conveyors are installed under the hoppers, effecting continuous removal of fly ash from these collection points.
TABLE 6 TYPES OF BOTTOM ASH SYSTEMS

<table>
<thead>
<tr>
<th></th>
<th>Mechanical</th>
<th>Hydraulic</th>
<th>Pneumatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Burning</td>
<td>P</td>
<td>A (1)</td>
<td>U (2) (4)</td>
</tr>
<tr>
<td>Spreader-Stoker Firing</td>
<td>P</td>
<td>A (3)</td>
<td>A (4)</td>
</tr>
</tbody>
</table>

Key: P = Preferred A = Acceptable U = Unacceptable

Notes: (1) The ash hopper is of the "bath tub design" in which a hydraulic plunger provides forced removal of ash.

(2) Large pieces of unburned MSW and ash may not discharge from hopper.

(3) Boiler setting height above grade may have to be raised above a minimum value to accommodate the ash hopper geometry.

(4) The potential for a fire in the hopper exists due to dumping of burning material.

The ash is conveyed to transfer tanks which serve as feeders for the pneumatic vacuum portion of the system. This combined system can be used advantageously in situations where physical constraints such as nearness of the silo to the precipitator may preclude the use of 100 percent mechanical conveyor system (Fig. 6).

The various fly ash conveying system possibilities are shown in Table 7. Although the fly ash characteristics vary slightly between mass burning and spreader-stoker firing, no distinction is made in the equipment which comprises the fly ash system for either method of firing MSW.

CONSIDERATIONS FOR ASH STORAGE

No discussion of fly ash systems would be complete without mentioning ash storage facilities and special considerations required for the storage of ash derived from MSW.

To drastically reduce atmospheric air within the pneumatic conveying system and the ash storage silo, it is often found desirable to substitute flue gas for the air required by the system. The inerting characteristics of the flue gas help ensure that explosions do not occur. In order to minimize the effect of acidic condensation, piping from the collection hoppers to the ash silo can be insulated or heat traced to gain maximum benefit from the use of the flue gas.

This method has a drawback, however. The elevated conveying temperature impacts the design of the vacuum producer. With a higher inlet temperature to the vacuum producer, the heat of compression through the machine would exceed the normal metal temperature allowance. Either a water-ring design for the vacuum producer or a water spray to lower the temperature at the vacuum producer inlet should be specified. In either case, stainless steel should be specified for the vacuum producer because of the corrosion potential associated with flue gas.
FIG. 4 MECHANICAL FLY ASH SYSTEM
FIG. 5 PNEUMATIC FLY ASH SYSTEM
### TABLE 6 FLY ASH EVACUATION AND TRANSPORTATION

<table>
<thead>
<tr>
<th>Ash Hopper Evacuation - Continuous</th>
<th>Mechanical</th>
<th>Pneumatic</th>
<th>Mechanical-Pneumatic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Ash Hopper Evacuation - Intermittent</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Ash Conveying to Storage - Continuous</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash Conveying to Storage - Intermittent</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

### TABLE 7 TYPES OF FLY ASH SYSTEMS

<table>
<thead>
<tr>
<th></th>
<th>Mechanical</th>
<th>Pneumatic</th>
<th>Mechanical-Pneumatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Burning</td>
<td>P</td>
<td>A (1)</td>
<td>A</td>
</tr>
<tr>
<td>Spreader-Stoker Firing</td>
<td>P</td>
<td>A (1)</td>
<td>A</td>
</tr>
</tbody>
</table>

Key: P = Preferred, A = Acceptable

Notes: (1) Although acceptable, 100% pneumatic conveying would be the least desirable system configuration for the reasons previously cited.
A related scheme for system inerting analyzes the oxygen content of the conveying medium. Any time the oxygen content rises above 10 percent, nitrogen is injected into the pneumatic branch lines. This inerting agent travels through the system providing protection against possible explosions. Its use is discontinued when the oxygen falls below 10 percent. The silo can also be inerted on a continuous basis, but this has generally been found to be economically unjustified, due to the cost of nitrogen.

Exploration protection for silos is available in two distinct forms: active and passive.

Active Silo Protection

This method utilizes an explosion detection and suppression system. This type of system senses the onset of an explosion and suppresses it in a fraction of a second by using explosive actuators to detonate spheres containing chemical agents. This system is electrically and mechanically complex, but it provides excellent backup for those times when, due to unforeseen circumstances, all other protective measures have failed.

Passive Silo Protection

As opposed to the aforementioned "active" system, a "passive" protection system utilizes explosion panels on the storage silo. The concept involves providing an opening large enough for the expanding gases to escape without over-pressuring the equipment. The opening is covered by a vent which is pushed open as the pressure develops [10]. For proper silo protection, a certain computed area of panel surface is required. This area is directly dependent on the volume of the silo, but it is possible that the required square footage of panel surface may equal that of the entire upper circumference of the silo, giving it a Swiss cheese-like appearance. The panels' advantages are low initial cost and minimal maintenance; their disadvantage is that the silo may need additional reinforcement to counteract the loss of plate surface from the upper silo shell. Depending on the preferences of the plant operators, either active or passive systems — or both — can be installed for silo protection.

In conjunction with either "active" or "passive" methods of silo protection, a fire extinguishing system comprised of automatic sprinklers, located within the bag filter and the silo, can provide extra assurance against system unavailability. The sprinklers will prevent fires from becoming uncontrollable while conversion to safe system operation is executed.

**STORAGE SILO ALTERNATIVE**

Since the ash storage silo appears to possess so many areas of operational, reliability and safety concern, the obvious question is, "Can the silo be eliminated?" The answer is both "Yes" and "No": "Yes", if the engineer can implement an all-mechanical method of ash conveying and "No", if the engineer is forced to use a pneumatic conveying system.

The mechanical system can, of course, use a conventional silo for ash storage identical to that used on a pneumatic system but without the necessity for ash/flue gas separating equipment. A better concept is to utilize an arrangement in which conditioned fly ash can be delivered directly to truck trailers. Since the conveying system runs continuously, two trailer units should always be available. The single cab unit will haul a full trailer of ash to the disposal site, while the remaining trailer unit continues to receive ash.

An adjunct to the mechanical conveying plan is the use of a weather-protected, 3-sided concrete bin for temporary or emergency ash storage. Dry ash conveyed to the 3-sided bin is conditioned with water to prevent subsequent dust problems. The ash conditioners then discharge to overhead belt or flight conveyors which transport the ash directly to waiting trailers or the conveyors can distribute the ash along the floor of the bin if trailers are not available. A front-end loader can be employed to transfer ash to the trucks in the event of ash being deposited on the floor of the bin. Advantages of the 3-sided bin include no elevated storage, no silo pluggage, more flexibility, fewer problems with ash freezing, and reduced maintenance.

**EFFICIENCY**

In today's climate of fiscal and environmental accountability, systems efficiency cannot be over-emphasized. Implementation of a mechanical bottom ash system will allow significant savings in horsepower usage. A typical bottom ash mechanical system consisting of submerged scraper conveyor, low pressure water pumps for closed-loop recirculation, and auxiliary conveyors to transport the ash to a truck loading station has a typical installed horsepower rating of 30 hp (22 kW). A comparable hydraulic bottom ash system, consisting of wet ash hopper, high and low pressure water recirculation pumps and de-watering tanks has a typical installed horsepower rating of 210 hp (157 kW) [11]. Since the mechanical system uses no water for sluicing, its water consumption is typically one-third of the hydraulic system's requirement.

The amount of operator attention necessary for the mechanical bottom ash system is much less than with the
FIG. 6 MECHANICAL-PNEUMATIC FLY ASH SYSTEM
other types of systems. Since the system runs continuously, a quick verification by zero-speed switches assures the machinery is functioning properly. Conversely, a hydraulic system is comprised of complicated equipment and controls which demand a higher level of attention, and a pneumatic system often needs manual assistance to encourage the ash to move from the storage hopper to the pipeline.

An efficiency comparison can also be made for fly ash systems. As with the mechanical conveyor for bottom ash, fly ash conveyors are inherently low in horse power usage. A typical mechanical fly ash arrangement consisting of eight flight conveyors discharging to a silo would have 40 hp (30 kW) installed. A similar straight pneumatic system would be rated at approximately 150 hp (112 kW), while the hybrid mechanical-pneumatic system would be approximately 100 hp (75 kW). Even though the mechanical conveyors run continuously, their total energy consumption is considerably less than the total required by an intermittent pneumatic system which operates four hours per shift.

The mechanical fly ash system has simpler controls — interlocking zero-speed switches readily prove correct operation of the equipment. The pneumatic fly ash arrangement, on the other hand, is burdened with complicated control logic. An elevated level of understanding on the part of the operators is mandatory in order to control and maintain the system.

ECONOMIC CONSIDERATIONS

In evaluating the overall economics of each bottom ash and fly ash system, as shown in Tables 5 and 7, the following criteria were considered:

- First Cost
- Auxiliary Power Cost
- Maintenance Cost
- Availability Cost

All costs are based on plant capacities of 2000 tons (1810 t) per day of MSW. The First Costs of the equipment include erection and equipment startup costs associated with the particular type of system.

Auxiliary Power Costs are based on accepted standard charge of $50 per kW-h per day and an installed horse-power charge of $600/hp ($448 per kW) [12].

Maintenance Costs, i.e., inspection, lubrication and replacement of worn parts, assume that the equipment manufacturer's recommended routine maintenance is performed. All replacement part costs are in 1983 dollars.

Unit Availability Costs utilize the mechanical system as the base comparison. A paper presented at the 1980 Coal and Ash Handling Conference of the Electric Power Research Institute [13] stated an average forced outage time of 9.3 hr per year for mechanically conveyed ash systems.

Ash System capital costs are affected to a great extent by equipment arrangement as well as unit size. Larger furnaces call for longer and higher capacity conveyors. Flue gas particulate removal equipment is sized according to dust loading, which increases or decreases in direct relationship to the amount of fuel fired and its ash content.

The location of ash storage facilities relative to ash collection points in the boiler house is very important in determining both costs and system design capacity. As dewatering tanks, fly ash silos and truck loading stations are located farther from the ash collection points, greater lengths of piping or mechanical conveyors are required and greater operating power must be expended.

BOTTOM ASH SYSTEMS

A relative comparison of costs for different bottom ash systems is given in Fig. 7.

The result of this comparison shows a mechanical system to be more economically favorable in all cases over a hydraulic system. In comparing pneumatic systems to mechanical, First Costs favor mechanical systems. The costs reflected here include the use of a 3-sided storage bin for the mechanical system. Due to an absence of information in this area, the data used in the formulation of the unit availability bar graph do not account for fires or explosions which may occur in a pneumatic system.

FLY ASH SYSTEMS

Figure 8 reflects a similar comparison of costs related to fly ash systems with the base system being the mechanical system.

Comparing costs for the three systems reveals that the mechanical system would be less than either the 100 percent pneumatic or the combination mechanical-pneumatic system. This includes fire protection equipment costs for pneumatic conveying with no consideration for any effects that fires or explosions would have on unit availability. The mechanical system is assumed to have a 3-sided bin for ash storage. Typically, a 3-sided bin constructed of concrete will have First Costs approximately 67 percent that of a steel silo with comparable storage volume.
CONCLUSION

Ash derived from the burning of MSW has characteristics unique from those associated with coal ash. In consideration of this fact, modern management of refuse ash mandates that many of the traditionally accepted methods of ash conveying and storage be set aside. This paper proposes that a contemporary refuse ash system embodies the concept of mechanical conveying as the best solution to this material's physical difficulties. In the interest of eliminating storage problems in hoppers and silos, reducing water and horsepower usage, lessening maintenance, and providing simpler and safer system operation, continuous mechanical conveying should be adopted as the Industry Standard for ash management on refuse-fired boilers.

REFERENCES


**Key Words:** Ash • Corrosion • Explosion • Fly Ash • Maintenance • Materials Handling • Refuse Derived Fuel