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Reference Number
7

Section

MULTIPLE-CHAMBER INCINERATORS FOR BURNING WOOD WASTE

INTRODUCTION

Although a small part of the wood waste produced from lumber mills and wood-working industries can be processed into useful products such as chip board, fireplace logs, and paper, the bulk of this waste is disposed of by incineration, open burning, or hauling to a dump. The most satisfactory air pollution solution is, of course, landfill disposal. The final choice of the method of disposal is primarily determined by economics and by the air pollution regulations existing in the locale.

There are, in general, three methods of burning wood waste. These are (1) open burning, that is, burning in a pile without any surrounding structure; (2) burning in single-chamber incinerators, including the tepee and silo structures; and (3) burning in multiple-chamber incinerators. Of these, the latter is the most satisfactory from an air pollution standpoint.

Open burning with no control over combustion air produces more air contaminants than single-chamber incinerators do with regulated air supply. The tepee and silo single-chamber incinerators also differ in combustion efficiency and emission of air contaminants.

Tepee incinerators are simple structures consisting usually of nothing more than a sheet metal shell supported by structural steel members in a shape similar to that of an Indian tepee. They are usually located at lumber mills and have limited control of primary combustion air. Many units employ blowers to supply air to the base of the burning pile to increase the burning rate. The metal shell is cooled by peripheral air, which flows upward and over the inside surfaces. Excessive combustion air admitted in this manner prevents good control of the combustion process and results in excessive smoke and other air contaminants.

A silo incinerator consists of a steel cylindrical chamber lined with high-duty refractory materials. The top of the cylindrical chamber usually tapers to a smaller diameter and extends upward, forming a stack to promote draft. Air is admitted through louvers located near the base of the structure. High temperatures can be maintained in the refractory-lined chamber, resulting in higher combustion efficiencies than in the tepee units. Single-chamber silo incinerators are not, however, satisfactory where air pollution is a serious problem, and have been found to emit particulate matter in excess of 12 pounds per ton of wood waste burned.

Description of the Refuse

Wood waste is produced by industry in a great many sizes and shapes ranging from fine sander dust to large pieces of lumber. Physical properties and combustion data for several common woods are given in Table 118. Green lumber at the mill varies widely in moisture content. For example, green redwood may contain over 50 percent moisture by weight, while construction-grade lumber such as Douglas fir contains from 10 to 25 percent moisture depending upon its age. Kiln-dried wood may contain as little as 5 or 6 percent moisture.

THE AIR POLLUTION PROBLEM

Burning of wood waste in open areas and at dump sites or in single-chamber incinerators is accompanied by dense clouds of smoke, fly ash, and disagreeable odors. Basically, these air contaminants are caused by incomplete combustion and are discharged in the form of particulate matter, aldehydes, hydrocarbons and organic acids, as well as smoke and fly ash. They are usually present in the greatest concentrations after the lightoff period or during times of heavy charging.

While single-chamber silo incinerators have been found to have particulate emissions in excess of 12 pounds per ton of wood waste, the particulate discharge from multiple-chamber incinerators designed to burn small wood particles ranges from 1-1/2 to 6-1/2 pounds per ton of wood waste burned, as shown in Table 119. Smoke is visible from a well-designed multiple-chamber incinerator only for a few minutes after lightoff and is occasionally accompanied by minute amounts of fly ash.

AIR POLLUTION CONTROL EQUIPMENT

Air pollution from the burning of wood waste can be reduced to a minimum through the use of multiple-chamber incinerators. By promoting complete combustion, multiple-chamber incinerators produce considerably less air pollution than is emitted from single-chamber incinerators or by open burning. Multiple-chamber incinerators discussed in the remainder of this part of the chapter are designed to burn all forms of wood waste--from large pieces of lumber to sawdust particles that may comprise from 10 to 100 percent of the total weight of the charge. The designs of mechanical feed systems are also included since the feed system must be properly integrated with the design of the incinerator to promote maximum combustion.

DESIGN PROCEDURE

The fundamental principles of combustion discussed in the first part of this chapter are applicable to designing these incinerators. Where 10 percent

Table 119. SOURCE TEST DATA FOR MULTIPLE-CHAMBER INCINERATORS BURNING WOOD

Item	Units	Test No.				
		1	2	3	4	5
Incinerator capacity	lb/hr	150	350	750	1,000	3,000
Normal burning rate	lb/hr[a]	170	300	740	1,055	2,910
Moisture content of refuse	wt %	10	5	10	25	10
Stack volume	scfm	420	557	3,260	3,300	15,300
Secondary chamber temperature	°F	1,600	1,400	1,500	1,850	1,600
Particulate matter	gr/scf at 12% CO_2	0.058	0.038	0.095	0.23	0.11
Particulate matter	lb/ton[b]	2.0	1.4	3.2	6.6	3.6
Sulfur dioxide	lb/ton[b]	0	0	0	0	0
Carbon monoxide	lb/ton[b]	0	0	0	0	0
Organic acid--as acetic	lb/ton[b]	0.8	1.2	0.54	0.85	1.2
Aldehydes--as formaldehyde	lb/ton[b]	2.0	1.9	0.8	3.0	6.0
Hydrocarbons--as hexane	ppm	9	9	9	9	9

[a] Burning rate based on stack analysis.
[b] Pounds of contaminants per ton of wood burned.

or more of the wood waste is in the form of sawdust and shavings, it must be fed at a continuous rate by a mechanical feed system. Differences in some design factors from those given at the beginning of this chapter for hand-charged general-refuse incinerators generally reflect the higher temperatures developed from the exclusive and continuous mechanical charging of wood, and differences in the distribution of combustion air.

The gross heating value of kiln-dried wood is 9,000 Btu per pound and is represented by the upper curves of Figures 310 and 311. These curves can be used to determine grate loading and average arch height, respectively. Other design factors differing from those for general-refuse incinerators are given in Table 120. These design factors include secondary chamber cross-sectional areas, inlet air port sizes, and other values and proportions.

An illustrative problem at the end of this part of the chapter shows how these factors are used to design a multiple-chamber incinerator with a mechanical feed system. The calculations in this problem fall into three general categories: (1) Combustion calculations based upon refuse composition, projected air requirements, and heat transfer; (2) gaseous flow calculations based upon the products of combustion at elevated temperatures; and (3) dimensional calculations based upon equations determined empirically from source testing.

Chemical properties and combustion data for average wood and Douglas fir, given in Table 118, and similar values for other kinds of wood can be used to determine the weights, velocities, and average temperatures of the products of combustion.

For calculation purposes, the burning rate and wood waste composition are assumed constant, and the incinerator is considered to be under relatively steady-state conditions. Calculations are always based upon refuse that is the most difficult to burn. Heat losses by radiation, heat stored in refractory, and heat content of the residue are assumed to average 20 to 30 percent of the gross heating value of the refuse during the first hour of operation. These heat losses drop to 10 to 15 percent after 4 or 5 hours of operation.

To determine the cross-sectional flow areas of the secondary ports and chambers, only volumes and temperature levels of the products of combustion are required. The temperature gradient in which the products of combustion cool as they pass from the flame port to the stack are averages based upon source tests of similar incinerators.

The calculated overall average gas temperature should be about 1,300°F based on 200 percent excess combustion air and the 20 to 30 percent heat losses. The calculated temperatures are not flame temperatures and do not indicate temperatures attained in the flame port or mixing chamber.

Indraft velocities through the ignition chamber air ports are assumed to average 900 fpm, equivalent to a velocity pressure of 0.05 inch WC, while indraft velocities through the secondary air ports av-

Table 120. DESIGN FACTORS FOR MULTIPLE-CHAMBER INCINERATORS FOR BURNING WOOD WASTE

Item and symbol	Recommended value and units	Allowable deviation
Primary combustion zone:		
Grate loading, L_G	10 Log R_c; lb/hr-ft^2 where R_c equals the refuse combustion rate in lb/hr (refer to Figure 310)	± 10%
Grate area, A_G	$R_c \div L_G$; ft^2	± 10%
Average arch height, H_A	4/3 $(A_G)^{4/11}$; ft (refer to Figure 311 and + 10% curve)	----
Length-to-width ratio (approx):		
Retort	Up to 500 lb/hr, 2:1; over 500 lb/hr, 1.75:1	----
In-line	Diminishing from about 1.7:1 for 750-lb/hr to about 1:2 for 2,000-lb/hr capacity. Oversqaure acceptable in units of more than 11-ft ignition chamber length	----
Secondary combustion zone:		
Gas velocities:		
Flame port at 1,900°F, V_{FP}	50 ft/sec	± 20%
Mixing chamber at 1,550°F, V_{MC}	25 ft/sec	± 20%
Curtain wall port at 1,500°F, V_{CWP}	20 ft/sec	± 20%
Combustion chamber at 1,200°F, V_{CC}	5 to 10 ft/sec; always less than 10 ft/sec	----
Mixing chamber downpass length, L_{MC}, from top of ignition chamber arch to top of curtain wall port	Average arch height, ft	± 20%
Length-to-width ratios of flow cross sections:		
Retort, mixing chamber, and combustion chamber	Range: 1.3:1 to 1.5:1	----
In-line	Fixed by gas velocities due to constant incinerator width	----
Combustion air:		
Air requirement, batch, or continuous charging	Basis: 200% excess air. 100% excess air admitted into ignition chamber: 50% theoretical air through mixing chamber air ports and 50% theoretical air through curtain wall air port or side air ports.	----
Combustion air distribution, % of total air required:		
Overfire air ports	60%	----
Underfire air ports	6%	----
Mixing chamber air ports	17%	----
Curtain wall port or side ports	17%	----
Port sizing, nominal inlet, velocity pressure, and velocity (without oversize factors), in. WC or fpm:		
Overfire port	0.051 or 900	
Underfire port	0.051 or 900	
Mixing chamber port	0.062 or 1,000	
Curtain wall port or side port	0.062 or 1,000	
Furnace temperature:		
Average temperature, combustion products at 200% excess air	1,300°F	± 20°F
Auxiliary burners:		
Secondary burner (if required)	2,500 to 5,000 Btu per lb of moisture in the refuse	
Draft requirements:		
Theoretical stack draft, D_T	0.15 to 0.35 in. WC	----
Available primary air induction draft, D_A (assume equivalent to inlet velocity pressure)	0.05 to 0.10 in. WC	
Natural draft stack velocity, V_S	Less than 25 ft/sec at 1,100°F	----

erage 1,000 fpm (0.06 in. WC). The incinerator draft system should be designed to produce a negative static pressure of at least 0.05 inch WC in the ignition chamber.

Primary air ports for continuously fed incinerators are sized for induction of theoretical plus 100 percent excess air. Ten percent of this air is admitted through ports located below the grates, and 90 percent, above the grates. Additional primary air can be admitted by opening the charging door when necessary. Air is induced into the mixing chamber not only to support combustion but also to cool the combustion gases and prolong the service life of the refractories. Mixing chamber air ports located in the bridge wall are sized to admit 50 to 100 percent of theoretical air. Air is sometimes admitted to the combustion chamber through air ports located in the curtain wall and sized to admit an additional 50 percent of theoretical air.

Although some combustion air enters the ignition chamber along with the sawdust from the pneumatic conveying system, this air usually amounts to less than 7 percent of the total combustion air and can be neglected in determining the size of the primary air ports. Air ports are designed with the factors given in Table 120.

Unless the wood refuse is extremely wet, auxiliary gas burners are not required in the ignition chamber to initiate and sustain combustion. If products such as rubber, oily rags, and plastics are present in appreciable quantities in the wood wastes, they produce partially oxidized compounds that require high temperatures for complete secondary combustion. Thus, secondary burners should be installed in the mixing chamber with automatic controls to maintain the required high temperatures under all phases of operation.

Incinerator Arrangements

Incinerators for burning wood use both in-line and retort styles as shown in Figures 317 and 318. Incinerators with capacities of less than 500 pounds per hour are usually constructed as retorts. Units ranging from 500 to 1,000 pounds per hour may, however, follow either the in-line or retort style for the arrangement of chambers. In-line styles are recommended for incinerators with capacities in excess of 1,000 pounds per hour because of not only the inherent higher costs of the retort but also the difficulties in cooling the internal walls. A retort-type incinerator with a prefabricated steel shell is shown in Figure 318. A single-chamber, silo-type incinerator can be converted to multiple chamber by attaching a dutch oven consisting of an ignition chamber and a mixing chamber as depicted in Figures 319 and 320.

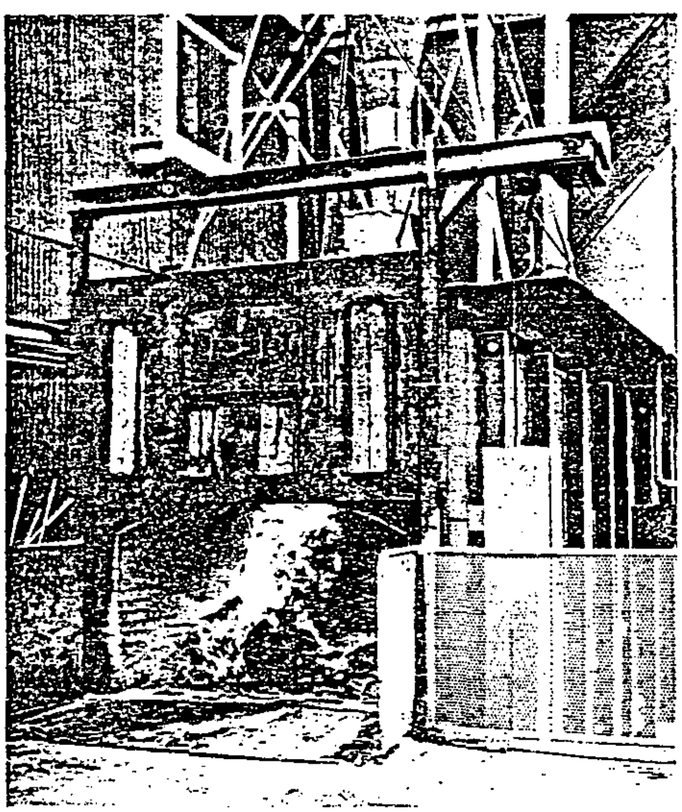

Figure 317. A 2,000-lb-per-hour, in-line multiple-chamber incinerator (Metro Goldwyn Mayer, Inc., Culver City, Calif.).

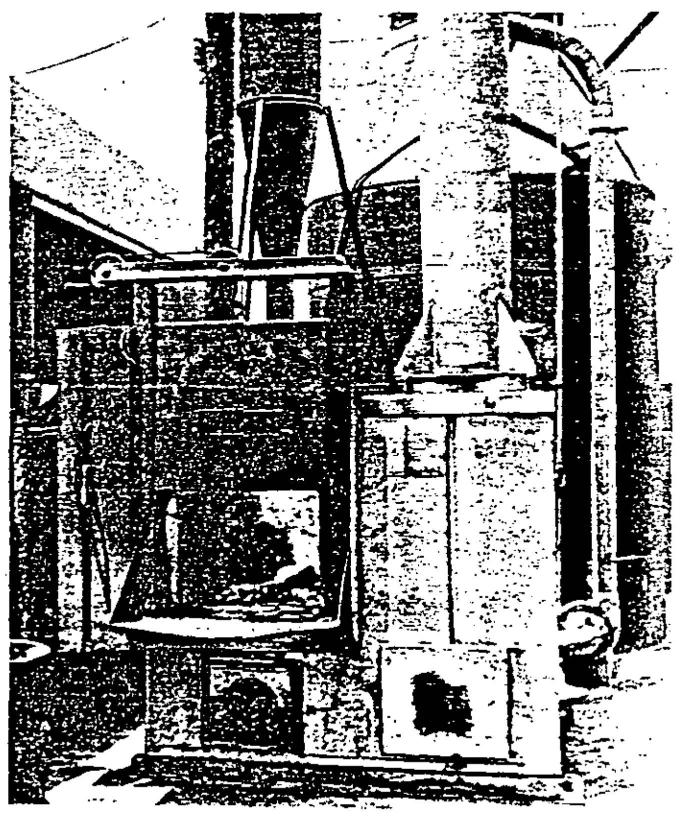

Figure 318. A 150-lb-per-hour, retort multiple-chamber incinerator (Acme Woodcraft, Los Angeles, Calif.).

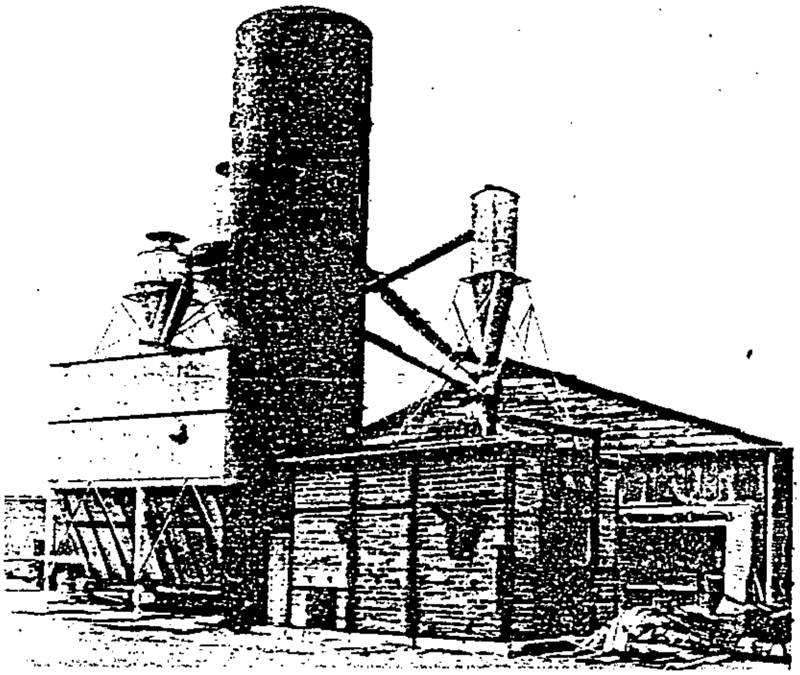

Figure 319. A 1,000-lb-per-hour, in-line multiple-chamber incinerator (silo conversion) (Orban Lumber Co., Pasadena, Calif.).

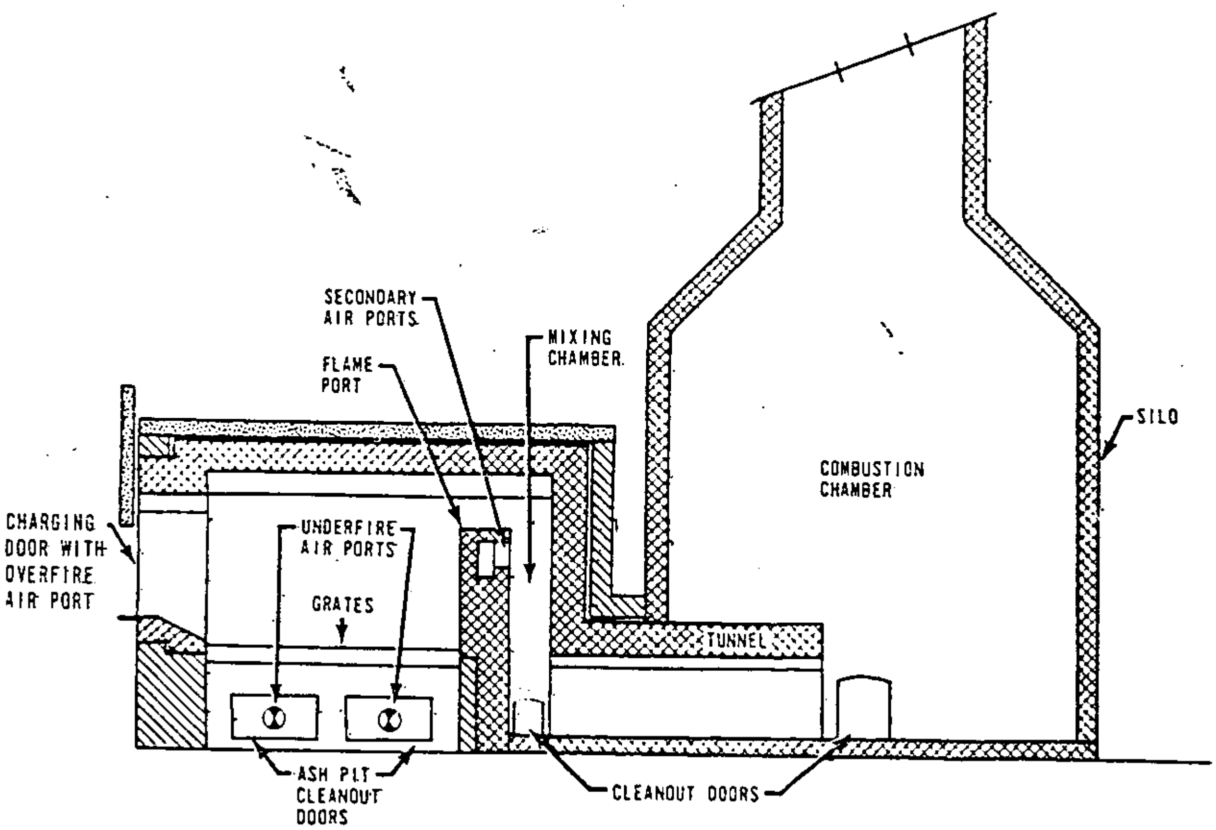

Figure 320. Schematic diagram of an in-line multiple-chamber incinerator (silo conversion).

In the design of the silo conversion, the size of the ignition chamber and mixing chamber attached to an existing silo is limited by a maximum allowable gas velocity of 10 fps through the horizontal cross-sectional base of the silo, or by the effective draft developed by the stack. Effective draft, in turn, is limited by the height of the silo and its internal dimensions.

If the attachment of an ignition and mixing chamber to a silo results in a gas velocity through the base of the silo of less than 5 fps, a refractory tunnel with a cross-sectional area equal to the curtain wall port area should extend from the curtain wall halfway across the base of the silo. The tunnel acts as an extension of the mixing chamber and provides additional flame residence time and turbulence necessary to complete the combustion process.

DESIGN PROCEDURE FOR MECHANICAL FEED SYSTEMS

During the development of the multiple-chamber incinerator, hand charging of sawdust and intermittent delivery of sawdust from local exhaust systems serving woodworking equipment were found to smother the flames periodically in the ignition chamber and thus cause excessive smoke. To overcome this problem, a feed system was developed for delivering small wood particles to the ignition chamber at a constant rate and thus sustain continuous burning over the entire surface of the pile. This system, illustrated in Figure 321, consists basically of a surge bin for holding sawdust and wood chips from local exhaust systems serving woodworking equipment. Screw or drag conveyors in the bottom of the surge bin move the wood waste at a uniform rate to the pickup point of a pneumatic conveying system. The pneumatic conveyor transfers the waste to a cyclone where the waste drops into the ignition chamber.

Surge Bin

Bins usually fabricated of sheet metal are designed in such a way as to augment gravity flow of sawdust and wood chips to the conveyor at the bottom of the bin. Waste is produced in a wide variety of sizes and shapes, ranging from fine sander dust to large chips from hoggers. Gravity flow of material is a complex function of the composition, size, shape, density, packing pressure, adhesive qualities, and moisture content. For example, pine wood shavings do not flow as easily as hardwood shavings of identical size and shape do because the resin content of the pine wood imparts an adhesiveness hindering the flow. The flow characteristics of a particular wood waste are, therefore, of primary importance in the final selection of the shape of the bin.

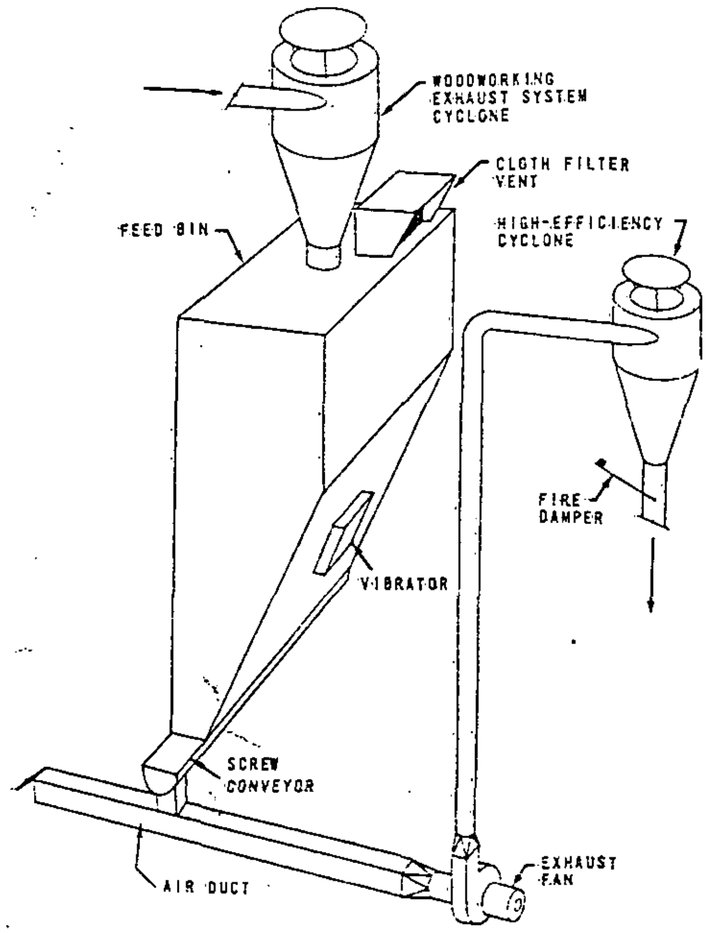

Figure 321. Diagram of a mechanical feed system.

Wood wastes that exhibit poor flow characteristics should be handled in bins constructed with vertical sides and screw or drag conveyors covering the entire flat bottom of the bin, as shown in Figure 322. If the wood waste has fairly free flow characteristics, a bin with four vertical sides and a sloping bottom may be used, as shown in Figure 323. The included angle between the vertical side and sloping bottom should not exceed 45 degrees. Wood waste that exhibits ideal flow characteristics may use a vee-bottom bin, as depicted in Figure 324. The included angle between sloping sections should not exceed 60 degrees for most efficient operation.

Although good bin design assists the flow of sawdust to the conveyors, bins with sloping bottoms require mechanical agitators or vibrators to prevent bridging. Vibrators are generally superior for this purpose since reciprocating and rotating bar agitators tend to shear and bend out of shape under heavy loads. To be most effective, vibrators are usually mounted about one-fourth of the distance from the base of the sloping bottom of the bin, which is usually constructed of a large, unsupported section of sheet metal. This method of construction permits transmission of vibration more easily than transmission from sloping sections rigidly supported with stiffened angles or steel structural members. If the bottom is so large as to require some type of external cross-sectional support, the support members should be attached only at the edges of the section.

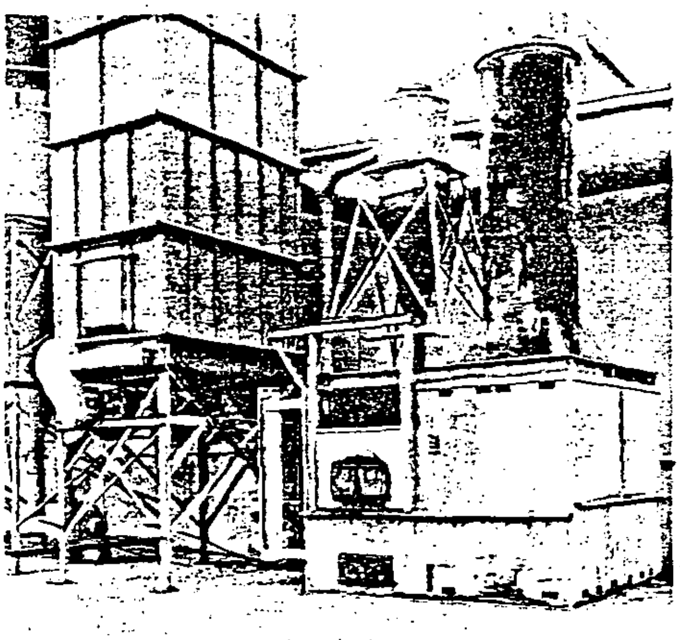

Figure 322. Vertical-sided feed bin with four parallel screw conveyors (Brown Saltman Furniture Co., Los Angeles, Calif.).

Vibrators operating continuously may cause the wood waste to pack and bridge in the bottom of the bin. To remedy this condition, the frequency of vibration or the amplitude of the vibratory stroke may be changed, or a mechanical timer may be installed to actuate the vibrators at desired intervals.

Screw or Drag Conveying

Screw or drag conveyors are placed in the bottom of a feed bin to remove sawdust and shavings from the bin at a regulated rate. Screw conveyors are preferred, except where long, tough, fibrous shavings are to be conveyed. Since material such as this would bind in conveyor flights, the more expensive drag conveyor must be used.

Screw conveyors with variable pitch are recommended over screws with uniform pitch because they permit more even loading of the screw along the entire length and thus minimize the compressing of sawdust and shavings causing bridging above the discharge end of the screw. Because relatively large pieces of wood may enter the conveying system, screw conveyors should be at least 6 inches in diameter to ensure their passage.

Regulation of the flow of wood waste is dependent upon the bulk density of the waste to be handled as well as upon the number, diameter, and speed of the screw conveyors. The bulk density of most wood wastes varies from 4 to 12 pounds per cubic foot, depending upon the kind of wood processed and the shape of the particles. Determination of the density must be based upon sawdust in its compressed form at the bottom of the bin, rather than in a loose form. Once the density has been established, the type of bin selected, and number of screws determined, the diameter and speed of the screws can be calculated. Provisions should also be made for a gear head or varidrive to regulate the speed of the conveyors so that they supply wood waste over a range of 33 to 100 percent of the burning capacity of the incinerator.

To prevent sawdust from being aspirated into the pneumatic conveying system faster than the normal delivery rate of the screw, conveyors should extend at least three screw diameters beyond the end

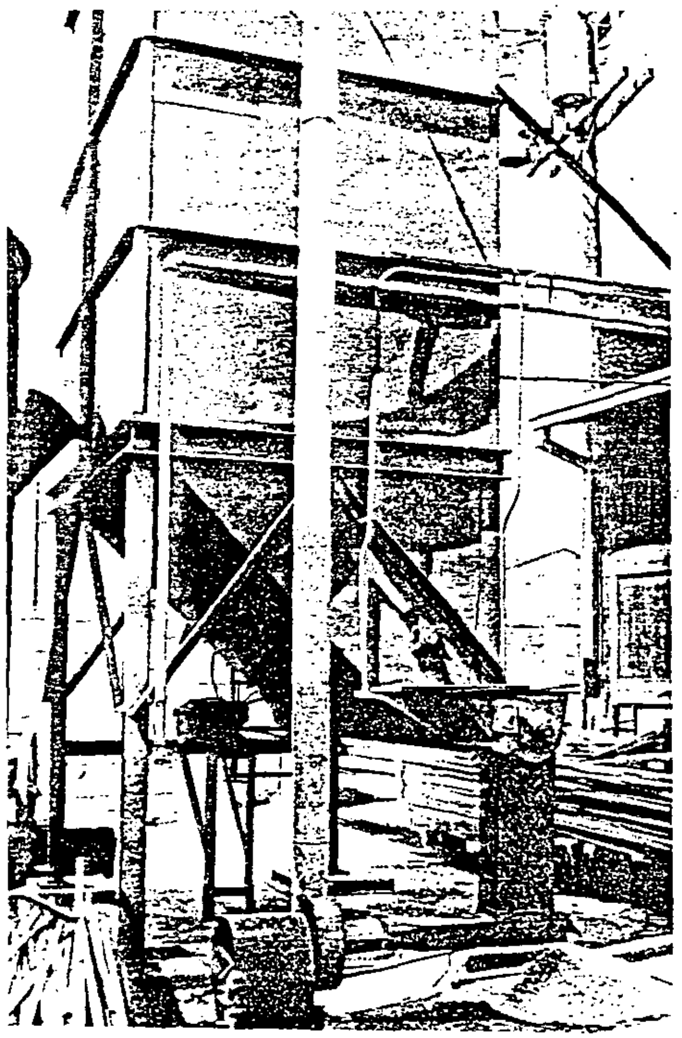

Figure 323. Feed bin with sloping bottom (California Moulding and Trim Mfg. Co., Los Angeles Calif.).

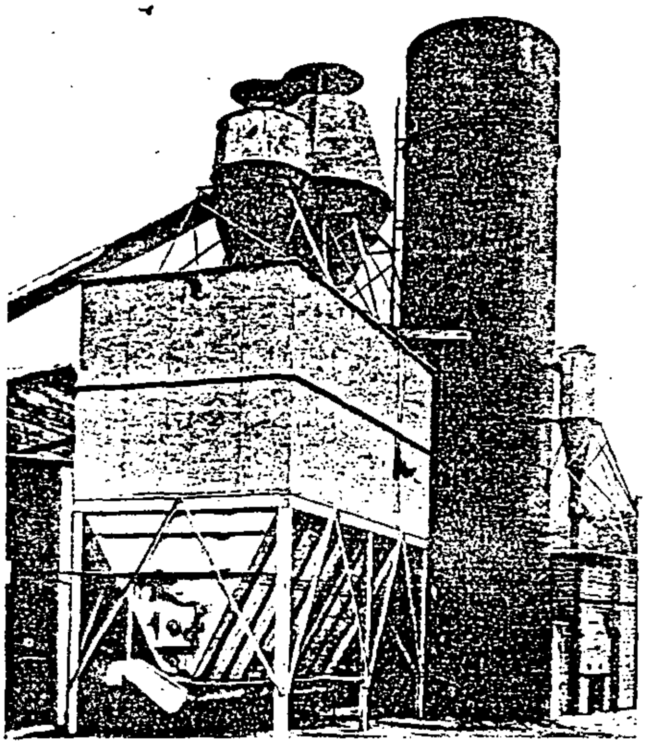

Figure 324. Feed bin with vee bottom (Orban Lumber Co., Pasadena, Calif.).

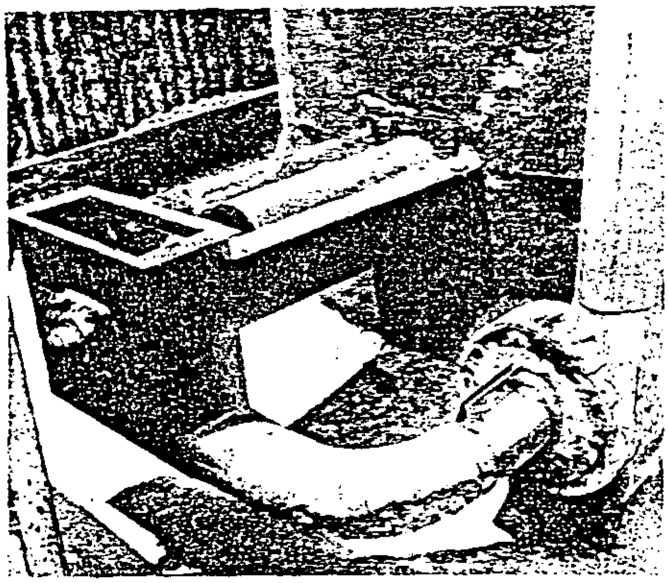

Figure 325. Screw conveyor with shroud (Acme Woodcraft, Los Angeles, Calif.).

of the bin, and the shrouds should be installed over the extended section, as shown in Figure 325. Shrouds are usually adjusted after the unit is in operation, to provide optimum clearance over the flights and prevent binding.

Pneumatic Conveying

While general design features for pneumatic conveying systems are discussed in the preceding chapter, a number of specific features should be considered in designing pneumatic conveying systems for wood waste incineration.

Pneumatic conveying systems are generally designed for a ratio of 2/3 cfm of conveying air per hour per pound of sawdust to be burned. About 10 percent of this conveying air should be admitted to the incinerator along with the wood waste to assist in spreading the particles evenly over the entire grate area and to maintain active flame over the surface of the burning pile. The amount of conveying air entering the ignition chamber may be regulated by installing either a butterfly damper in the top outlet duct of the cyclone separator, or spiral vanes within the cone of the cyclone separator.

Sawdust pickup and conveying velocities should be at least 3,000 fpm to prevent sawdust blockage in the ductwork. Blower motors should be oversized to accommodate occasional surges of sawdust through the pneumatic conveying system.

Cyclone separators used in conjunction with the blower are of the small-diameter, high-efficiency type with separation factors that exceed 100, as described in Chapter 4.

A flap-type damper equipped with a counterbalance weight should be installed at the bottom outlet of the cyclone separator. This damper is adjusted to close automatically when the blower is not in operation, which prevents the hot gases of the ignition chamber from damaging the sheet metal of the cyclone separator and also prevents smoke from being emitted to the atmosphere from the top of the cyclone. This damper should be constructed of 1/4-inch stainless steel plate since it is subject to intense radiation from the burning pile. By construction of a square-shaped damper with a square duct extending below, the damper is able to swing out of the way of the falling wood waste. The damper should be large enough to form a tight, overlapping seal with a smooth, stainless steel flange located below the round duct at the bottom of the cyclone separator.

To ensure proper operation, the equipment should be electrically interlocked to start simultaneously or in the following order: (1) Blower, (2) conveyors, (3) vibrators or agitators.

STANDARDS FOR CONSTRUCTION

While structural features of wood-burning incinerators are similar to those of general-refuse incinerators, wood-burning incinerators must be designed for greater stresses and strains caused by increased thermal expansion resulting from higher temperature operation. Refractories, therefore, are selected to resist not only normal abrasion from charging but also erosion, spalling, and slagging resulting from high-temperature, high-velocity flame impingement.

Refractories

Super-duty plastic refractory or super-duty fire clay firebrick are recommended for the interior walls and arches that come into direct contact with flames and hot gases, since temperatures usually exceed 2,000°F. Expansion joints with 1/2-inch minimum width should be installed for every 6-foot section of refractory. These joints must be sealed completely with high-duty ceramic packing with minimum service temperatures of 2,500°F. Packing of this type is necessary to prevent ashes from collecting in the open joints and fusing in such a way as to render the joint useless.

The first 10 feet of stack must be lined with high-duty firebrick or an equivalent castable refractory. The remainder of the stack may be lined with a lower duty material since flame impingement in this area does not normally occur. The charging door and other access doors, with the exception of the ash pit cleanout doors, should be lined with 120-pound-per-cubic-foot, ASTM Class 24, castable refractory.

The minimum heights for free-standing firebrick walls of given thickness are as follows.

Thickness of walls, in.	Unsupported height, ft
4-1/2	4
9	10
13-1/2	14

Firebrick walls extending above these heights should be held to exterior supports with stainless steel anchors that permit a differential rate of expansion. Walls constructed of plastic refractory should be anchored to exterior structural steel members on 18-inch centers.

Arches may be constructed of firebrick or plastic refractory. Firebrick arranged to form 60-degree arches should be limited to a maximum span of 5 feet 10 inches for 4-1/2-inch thickness and 8 feet for 9-inch thickness. Arches with spans greater than 8 feet should be constructed of suspended, super-duty, fire clay shapes or super-duty, plastic refractory. Plastic refractory used for this purpose must be suspended from refractory cones or stainless steel anchors spaced not more than 15 inches apart.

Grates

Two materials satisfactory for construction of grates are cast iron and castable refractory. Cast iron grates are available in a wide variety of sizes and shapes. They are of much heavier construction than those used in comparable general-refuse incinerators, to minimize deformation at high temperatures. Where blocks or scraps of wood are to be burned, bar- or channel-shaped grates should be employed, but when wood waste accumulated from woodworking equipment is to be burned, pinhole grates should be installed. Typical pinhole grates consist of 6-inch-wide by 24-inch-long by 3/4-inch-thick slab sections of cast iron with 1/2-inch holes on 2-inch centers. Grates of this type are capable of retaining small wood particles that might otherwise fall unburned into the ashpit.

Refractory grates are nearly always constructed in the form of 60-degree sprung arches. On incinerators of 250-pound-per-hour capacity or less, grates are constructed of ASTM Class 24 refractory 5 to 6 inches thick, with 1-inch holes on 5- to 6-inch centers. ASTM Class 27 castable refractory 6 to 8 inches thick, with 1-inch holes on 6- to 9-inch centers is used in larger incinerators.

Caution is required in operating incinerators with cast iron grates. Underfire air must not be unduly restricted nor should the ash pit be allowed to fill within 1 foot of the grates. Heat buildup in the ash pit from either condition can cause the grates to warp and sag. Misoperation of this type does not deform grates constructed of castable refractory. These grates are, however, susceptible to damage from careless stoking and cleaning.

When most of the charge consists of sawdust or similar small wood particles delivered by a uniform feed system, a solid hearth should be installed at the rear of the ignition chamber to prevent the introduction of excessive underfire air at this location. As the size of the incinerator increases, hearths are sometimes installed along the sidewalls also to prevent excessive underfire air. In any event, the hearth area should not exceed 30 percent of the total horizontal area of the primary ignition chamber.

Exterior Walls

Incinerators can be constructed with exterior walls of red brick or steel plate. Red brick exteriors are usually constructed of two layers of red brick bonded by a reinforced concrete center. Exterior steel plate may be of the thin, corrugated type used to back plastic refractory, or as heavy as 10 gauge to support interior brick construction.

Air Ports

Combustion air port controls should be constructed of cast iron not less than 1/2 inch thick. These ports should fit tightly to reduce air leakage to a minimum.

OPERATION OF INCINERATORS

Certain differences exist between the operation of wood-burning incinerators and general-refuse incinerators. The operator of a general-refuse incinerator generally relies on auxiliary burners to maintain temperatures for maximum combustion in the secondary chamber. The operator of a wood-burning incinerator, without provisions for auxiliary burners, is able to maintain adequate secondary chamber temperatures by proper charging and control of combustion air.

Generous amounts of clean dry paper are mixed with the wood for the initial charge. After the ignition chamber is one-half to two-thirds full, additional paper is placed on top of the pile to ensure quick flame coverage at the surface. It is important, in keeping smoke to a minimum, that only clean dry paper and dry scrap wood comprise the initial charge. After charging is completed, the paper is ignited near the front of the chamber and the charge door is closed. All combustion air ports are almost completely closed to restrict combustion air.

As burning proceeds, the incinerator passes through the most critical period of its operation. By observing the emissions from the stack, the necessary adjustments can be made promptly to reduce or eliminate smoke. Gray or white smoke emitted after lightoff indicates that the incinerator is cold. This smoke can be minimized or eliminated by closing all air ports. Smoke of this color usually ceases within a few minutes after lightoff when flames completely cover the refuse pile and fill the flame port. A few minutes later, black smoke may appear, resulting from a lack of adequate combustion air. These emissions can usually be eliminated by opening primary air ports and then the secondary air ports. If additional combustion air is required, it may be supplied by opening the charge door.

Although each incinerator has its own operating characteristics, the overfire and underfire air ports can usually be opened 5 to 10 minutes after lightoff, and the secondary port, 20 to 30 minutes later. If opening of the secondary ports results in gray or white smoke emissions, the ports should be closed immediately since the incinerator has not yet reached its normal operating temperature.

After attaining normal operating temperatures, maximum combustion is maintained by placing the mechanical feed system in operation or by hand charging at regular intervals.

Illustrative Problem

Problem:

Design a multiple-chamber incinerator to burn 1,000 pounds of Douglas fir waste per hour with a maximum moisture content of 10 percent.

Solution:

1. Composition of the refuse:

Dry combustibles	(1,000 lb/hr)(0.90) =	900 lb/hr
Moisture	(1,000 lb/hr)(0.10) =	100 lb/hr
Total		1,000

2. Gross heat input:

From Table 118, the gross heat of combustion of 1 pound of dry Douglas fir is 9,050 Btu/lb

(900 lb/hr)(9,050 Btu/lb) = 8,140,000 Btu/hr

3. Heat losses:

(a) Assume radiation, convection, and storage heat losses are 20 percent of gross heat input:

(0.20)(8,140,000 Btu/hr) = 1,625,000 Btu/hr

(b) Evaporation of contained moisture:

The gross heat of vaporization of water at 60°F is 1,060 Btu/lb

(100 lb/hr)(1,060 Btu/lb) = 106,000 Btu/hr

(c) Evaporation of water formed by combustion:

From Table 118, there is 0.563 lb of water formed from the combustion of 1 pound of dry Douglas fir.

$$(900\ \text{lb/hr})\left(\frac{0.563\ \text{lb}\ H_2O}{\text{lb}}\right)(1{,}060\ \text{Btu/lb})$$

= 537,000 Btu/hr

(d) Total heat losses:

a + b + c = total losses

1,625,000 Btu/hr + 106,000 Btu/hr + 537,000 Btu/hr = 2,263,000 Btu/hr

4. Net heat available:

8,140,000 Btu/hr - 2,268,000 Btu/hr = 5,872,000 Btu/hr

5. Weight of products of combustion:

From Table 118, there is 13.86 lb of combustion products from 1 pound dry Douglas fir