EPRI

Bottom Ash System Maintenance Guide

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Technical Report

Plant Maintenance Support

Reduced Cost

Equipment Reliability

FMAC

Bottom Ash System Maintenance Guide

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Final Report, October 2000

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REPORT SUMMARY

This guide provides information to personnel involved in the bottom ash system and its components, including good maintenance practices, condition monitoring, predictive and preventive maintenance techniques, probable failure modes, and troubleshooting guidance. The guide was developed primarily to provide detailed maintenance and troubleshooting information but also includes basic system information.

Background
Bottom ash system components incur excessive wear rates that require high maintenance activity and large maintenance costs. Therefore, proper monitoring and maintenance of this plant system are critical.

Objectives
- To give fossil power plant personnel an in-depth understanding of the operation of the bottom ash system
- To assist with the correct application of bottom ash system components
- To provide information on proper component installation methods
- To provide guidance on failure mechanisms and their causes
- To provide guidance on expected component life under various operating conditions
- To present recommended predictive (diagnostic), preventive, and corrective methods of maintenance to optimize component life and system operation
- To provide guidance on training documentation

Approach
User survey responses, failure modes and effects analysis, and industry failure data indicate that the major failure mechanisms acting on bottom ash systems and system components include erosion, corrosion, impact, fatigue, lubrication failure, and misalignment.

The major bottom ash system components affected by these failure mechanisms include the ash hopper wall and refractory, seal troughs, hopper sluice gates, crushers, pumps (centrifugal and jet), ash transport piping and conveyor systems, settling/surge tanks, dewatering systems, control systems, and mechanical bottom ash systems.

The recommendations contained in this report were developed from published literature and the experience and expertise of numerous users and manufacturers of bottom ash systems.

Results

The most effective actions taken by power plant personnel in minimizing the failures of the bottom ash system are routine surveillance, periodic inspection and lubrication, targeted predictive/preventive maintenance, precise alignment of equipment (including piping), material upgrades (where warranted by site-specific conditions), and equipment upgrades or modifications as needed. From the experience data collected from power plant personnel, original equipment manufacturers, and vendors, several industry best practices were identified:

- Periodically rotating accessible straight lengths of ash transport piping to more evenly distribute wear
- Using optimum refractory materials, anchors, and stabilization for each ash hopper application
- In close proximity to ash pumps, utilizing ash transport piping materials that are extremely resistant to both erosion and impact damage
- Performing routine surveillance to reduce the occurrence of unexpected failures and performing preventive maintenance during boiler outages to achieve high reliability during operating cycles of the generating unit

EPRI Perspective

Bottom ash system problems represent major expenditures for power plant operators. This guide provides information to give power plant personnel a better understanding of the system, its components and failure modes, and recommended predictive and preventive maintenance practices. It also provides guidance on troubleshooting bottom ash system problems.

Keywords

Bottom ash
Materials
Preventive maintenance
Predictive maintenance
Troubleshooting

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ABSTRACT

The bottom ash system in a fossil plant consists of components that incur excessive wear rates and thus require high maintenance activity, resulting in large maintenance costs. Due to these issues, it is one of the more critical plant systems to properly monitor and maintain.

Industry experience and survey responses indicate that similar bottom ash equipment often provides drastically different service life at different plants. This suggests that site-specific applications, operating conditions, or operating/maintenance practices may have a significant effect on the failure rates of systems and components.

This guide provides information on the application, operation, and maintenance of bottom ash systems. The information presented is intended to assist fossil power plant maintenance, operating, and engineering personnel in their efforts to improve bottom ash system performance. The significant causes of bottom ash system component failures are investigated and described, and methods to optimize service life and minimize maintenance costs through appropriate predictive and preventive maintenance are presented. The information in this guide should provide the foundation for an effective and efficient maintenance program.

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1
INTRODUCTION

A fossil power plant is composed of hundreds of systems and subsystems, all of which must function reliably to ensure the safe and efficient generation of electricity. All plant resources must be used cost-effectively and efficiently to enable a power producer to survive and thrive in today's competitive energy marketplace.

EPRI's Fossil Maintenance Applications Center (FMAC), in conjunction with member power producers, has identified several major systems that typically require a high level of preventive and corrective maintenance: one of these is the bottom ash handling system. Such maintenance-intensive systems jeopardize unit availability and place an undue burden on budgetary and manpower resources. In most coal-fired plants, the bottom ash handling systems require frequent component replacements and large expenditures of surveillance, operating, and maintenance efforts.

1.1 Purpose

This guide provides fossil power plant staff with information for establishing an effective maintenance program for their bottom ash systems using state-of-the-art components and methods developed by equipment manufacturers and users. Component applications outside the electric power industry have been investigated to provide a cross-functional perspective and take advantage of innovations in other heavy industries.

The guide outlines the most probable failure modes, describes appropriate predictive and preventive maintenance techniques, and provides information on the methods available to optimize service life and minimize maintenance costs through effective preventive maintenance and condition monitoring. References are provided for further detailed technical information on these recommended techniques.

Recommendations in this guide are based on published literature and the experience and expertise of numerous users and manufacturers. Data sources include the following:

- Power plant maintenance, operating, and engineering personnel
- Boiler original equipment manufacturers (OEMs)
- Bottom ash handling system OEMs
- Bottom ash handling component manufacturers and vendors
- Results of a comprehensive maintenance survey completed by FMAC members
- Literature provided by boiler and ash handling system and component manufacturers
- EPRI and other technical publications

A complete list of references is provided in Section 9.

1.2 Organization of Guide

This guide is organized in 11 sections and appendices as follows:

- Section 1 provides an introduction and general discussion of the guide’s purpose and organization.
- Section 2 is a glossary that defines terms and acronyms used throughout the guide or contained in typical bottom ash system technical literature.
- Section 3 provides technical descriptions of systems and components commonly used in the handling of bottom ash in the electric power industry.
- Section 4 explores potential misapplications of materials and equipment that can result in poor system reliability, accelerated component wear, and increased costs. Recommendations are given that should allow the user to determine the optimum application of materials and components at a given site.
- Section 5 describes common failure modes and recommends appropriate preventive and predictive maintenance activities and remedial courses of action.
- Section 6 recommends optimum troubleshooting strategies.
- Section 7 outlines suggested training requirements.
- Section 8 addresses safety concerns related to operating and maintaining bottom ash systems and recommends methods for minimizing personnel risk.
- Section 9 is a list of references used in the creation of this guide. Readers may wish to consult this literature for more detailed treatment of certain subjects.
- Appendix A is a summary of the Pop Outs distributed throughout this guide.
- Appendix B provides information on a hydrodynamic rotary seal technology that readers may wish to investigate for application in crushers.

1.3 Pop Outs

Throughout this guide, key information is summarized in “Pop Outs.” Pop Outs are bold lettered boxes which succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Pop Out is to emphasize information that will allow individuals to take action for the benefit of their plant. The information included in these Pop Outs was selected by FMAC personnel and the consultants and utility personnel who prepared and reviewed this guide.

The Pop Outs are organized according to three categories: O&M Costs, Technical, and Human Performance. Each category has an identifying icon, as shown below, to draw attention to it when quickly reviewing the guide.

Key O&M Cost Point

Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent injury or damage or ease completion of the task.

Appendix A contains a listing of all key points in each category. The listing restates each key point and provides reference to its location in the body of the report. By reviewing this listing, users of this guide can determine if they have taken advantage of key information that the writers of the guide believe would benefit their plants.

2 GLOSSARY

2.1 Definitions

Angle of Repose - The angle from the horizontal that an unrestrained pile of ash assumes when poured onto a horizontal surface. The angle of repose is a measure of internal shear strength of the ash in bulk, and hence, of flowability.

Ash - See Fly Ash or Bottom Ash.

Ash Mass Equivalency - Pounds of ash per million Btu heat content of fossil fuel.

Ash Pit Hopper - Archaic name for the bottom ash hopper, either water-impounded or dry, that is intended to receive and temporarily store bottom ash as it falls through the boiler throat.

Balanced Valves - Branch isolating valves, usually on sluice systems, adapted from butterfly valves. The names derive from the fact that fluid forces on each side of the butterfly are equal (balanced), facilitating opening and closing.

Basalt - A mineral substance of very high hardness and excellent abrasion resistance, which is used as a wear lining in ash handling equipment.

Bin - An ash storage structure, usually round and elevated to allow unloading from the bottom. Typically constructed from poured reinforced concrete, concrete stave, or fabricated steel. Radial tile was also used as construction material for smaller round bins prior to approximately 1970.

Bituminous - The principal steam coal found mainly in the middle eastern and middle western states. From the standpoint of ash handling and steam production, bituminous coal is better than either subbituminous coal or lignite. Because of its higher sulfur content, however, its use has diminished.

Booster Sections - Sections of reduced diameter piping placed in a pipeline conveyor. They are intended to increase velocity at points that are either potentially or actually prone to plugging. The inclusion of booster sections is usually a post-installation fix for these plugging problems.

Bottom Ash - Solid byproduct of combustion that has sufficient mass, either as a monolith or as an agglomeration of smaller particles, to fall against the gas flow to the bottom of the furnace.

Capacity, Net - The specified capacity of the ash handling system over a sustained period of time. Net capacity should include allowances for sequencing, irregularities of feed, instrumentation lag, and component response and wear. It should also be based on an average conveying distance from a "central" intake.

Clinker - Fused chunks of bottom ash.

Clinker Grinder - Also called *clinker breaker*. See Crusher.

Collection Hopper - The hoppers placed in the furnace ducting, primarily at changes of direction, where ash falls out of the gas stream. Also refers to the storage hoppers provided for material collected in electrostatic precipitators and baghouses.

Concentration - See Weight Concentration and Volume Concentration.

Couplings - Pipe conveyor connection sets, including flanges, gaskets, and fasteners.

Crusher - Rotary machine used for reducing the size of large ash clinkers so they can be safely and easily passed through pipe conveyors. Principal designs are single-roll and counter-rotating double-roll. Usually a component in bottom ash systems; less frequently used to size economizer ash.

Conveying Velocity - The design velocity at a design point carefully chosen so that the velocity everywhere in the pipeline exceeds an acceptable minimum.

Cylinders - Air or hydraulic actuators used to sequence and control many types of equipment used in ash handling systems.

Dewatering Bin - Temporary storage vessels used in sluice (wet) ash systems. Dewatering bins separate the ash from the transport water so that the ash can be transported by truck or rail to the ultimate disposal site.

Discharge Door - A door provided on bottom ash hoppers and dewatering bins through which stored ash is unloaded.

Drag Chain Conveyor - Also called *submerged scraper bar conveyor*. A means of continuously removing bottom ash from a water-impounded tank placed beneath a furnace. See Mechanical Bottom Ash System.

Enclosure Gate - Enclosure around the discharge door(s) of an ash hopper that provides a dust-tight or watertight transition from the discharge doors to the conveyor line.

Expansion Joint - A pipe fitting especially designed to accommodate movements in the pipeline without undue stress. Expansion joints are usually sleeve or bellows type.

Firebrick - Refractory brick used to line ash hoppers. Still used on smaller hoppers or industrial boiler hoppers. On large hoppers, firebrick has largely been superceded by refractory cement.

Flange Clamp - Loose circular or semicircular (flange clamp half) piece through which bolts pass for connecting bevel end pipe and fittings.

Flow Contactor - Electrical switch activated by fluid flow (air or liquid) used for process control in ash conveying systems.

Fly Ash - Particulate products of combustion that are light enough to become entrained in the gas stream and that would exit the stack if not removed by pollution control equipment.

Funnel Flow - Flow of material vertically above the outlet, which flows down and out first, with material close to the side walls sloughing off into the resulting void. Flow patterns largely depend on the geometry of the vessel. See also Mass Flow.

Gates - The preferred term for valves used in pneumatic pipeline ash conveyors. Available in various configurations, including butterfly, slide, swing disc, dome, and segment.

Grate - Framework of crossed or parallel metallic segments that is used to support burning coal, as in a stoker-fired boiler. Used alternatively with *grid* as a term to describe a device used to size ash and clinkers to dimensions that will not plug the system.

Grid - See Grate.

Guide - A restraint on a pipeline conveyor that restricts lateral movements but allows axial movement.

Handholes - Small removable panels or segments intended to allow internal access or facilitate internal inspection of ash handling components, including tanks, vessels, and pipeline fittings.

Hanger - A support on a pipeline conveyor, suspended from above, which allows some random movement. In the case of a spring hanger, movement is at a controlled rate.

High Level Switch - Used to alarm or stop the process when tripped. Intended to detect high ash and water levels.

Hopper - Ash collection and storage vessel.

Hydraulic Conveyor - Used to transport solids in a moving mass of liquid, usually in a pipeline but sometimes in a trench or flume.

Hydraulic Ejector - See Jet Pump.

Hydroveyor - Trade name of United Conveyor Corporation for a water-powered venturi type exhauster.

Jet Pump - A water-powered venturi device used to remove slurry or liquid from a vessel or sump to which the jet pump is hydraulically connected.

Lateral - Pipe fitting for merging flow from a branch into a main line.

Layout - A description of the routing of a pipeline or placement of other conveyor components.

Lignite - Low rank fuel found principally in Texas, North and South Dakota, and to a lesser extent, Louisiana. Heating value is less than 8,300 Btu per pound (19,306 joules per gram).

Loading - Expression for the concentration of particulate matter in a pipeline conveyor. Units for pneumatic conveyors are pounds of ash per pound of air. Hydraulic conveyor loading is expressed as weight percent, for example, 15% solids by weight.

Mass Flow - Flow of material from a silo or hopper such that the entire horizontal cross-section moves through the vessel at the same rate. Thus, the first material into the vessel is the first out, and vice versa. Flow patterns largely depend on the geometry of the vessel. See also Funnel Flow.

Mechanical Bottom Ash Conveyor - Equipment for mechanically dewatering and removing bottom ash from the bottom of a boiler. Also called *de-asher* and *submerged scraper conveyor*.

Mill Rejects - See Pyrites.

P.C. - Common abbreviation for pulverized coal, the fuel, and the firing method of the most prevalent type of utility boiler.

Poke Holes, Pressurized - Access holes into a hopper that incorporate a compressed air exhauster to prevent blowback of furnace gases through the poke hole when it is opened.

Pulverized Coal - See P.C.

Pyrites - Iron pyrites or the waste product from pulverizing coal; also called *mill rejects*.

Rat Holing - An extreme case of funnel flow out of a hopper or silo, whereby the material above the outlet vertically flows out and leaves a columnar void (rat hole) in the material, effectively stopping the flow.

Refractory - Heat-resistant materials, including firebrick, paving brick, and formable cements that are used in ash storage vessels directly subjected to furnace heat.

Refractory Anchor - Anchors, arc or resistance-welded to the inside skin of steel vessels, that reinforce and hold refractory cements applied to the inside of these vessels. They are primarily needed because of differential expansion between the steel vessel and the refractory material.

Rugosity - The inverse of sphericity. A cube has rugosity = 1.24.

Saltation - A term used to describe a particular solids pipeline flow pattern in which the solids pass back and forth between entrained flow and sliding flow. Solids are concentrated in the bottom part of the pipe during saltation.

Saltation Velocity - Velocity at which saltation occurs. See Saltation.

Seal Trough - A water-filled trough around the periphery of a bottom ash hopper, which is fixed to the hopper. A plate hanging vertically from the periphery of the boiler throat extends into the seal trough. The pressure created by the depth of water in the trough is designed to exceed, by a specified margin, the maximum boiler pressure. This nonsolid connection accommodates boiler movement without breaking the seal.

Settling Tank - Gravity water clarifier sized so that the rise rate of water in the tank does not exceed the settling rate of the particulates to be removed.

Slag - Ash that has been heated above the fusion point. Slag is an extremely hard, tough, and abrasive material. It is the principal ash product of a cyclone boiler.

Slag Breaker - Water-cooled steel arm that oscillates in a horizontal plane below the slag outlet of a cyclone boiler. It is intended to break the column of slag to prevent it from growing upward and plugging the slag outlet.

Slag Tank - Water-impound tank placed under cyclone boiler for quenching and temporary storage of slag.

Slug Flow - The movement of solids through a pipe as a very concentrated mixture, not all of which is in suspension.

Sluice Trench - Obsolete device (method) for transporting ash through trenches with the motivating force provided by built-in water nozzles spaced at regular intervals.

Sphericity - A physical characterization of the shape of particles that compares the surface area of the particle to that of a sphere of equal volume. A cube has sphericity = 0.806.

Subbituminous - See Coal and the Coal Deposits map. Generally taken as bituminous type coal with a heating value less than 10,500 Btu per pound (24,423 joules per gram).

Submerged Chain Conveyor - Also called *de-asher* and *submerged scraper conveyor.* See Drag Chain Conveyor.

Sump - A pit provided near ash handling equipment for cleanup purposes. Ash spills are hosed or washed into the sump, from which the ash is pumped as a slurry.

Surge Tank - In recirculating water systems, the tank that stores all the water used in the ash handling system.

T250 - Temperature at which slag has a viscosity of 250 centipoise (0.25 pascal second).

Target Plate - Heavy abrasion-resistant plate against which ash is discharged at the terminal of the conveyor.

Transition Hopper - Used in submerged drag bar bottom ash systems. This is the stationary structure between the bottom of the furnace and the drag bar trough, which is usually movable.

Vacuum Breaker - Vacuum relief valve used on pneumatic pipeline conveyors to interrupt the vacuum, allowing receiving equipment to dump accumulated ash.

Vacuum, Pressure Relief Valves - Venting devices placed on top of silos and on bottom ash door enclosures to prevent the structure from being pressurized or subjected to vacuums beyond its design range.

Valley Angle - The angle formed with the horizontal of two adjacent sides of a pyramidal ash storage hopper.

Velocity - Also called *conveying velocity*. If not further defined, it is usually taken to be the superficial velocity or the calculated velocity of a volume of fluid through a pipe of given cross-section. This is evaluated by the familiar relationship: $V = Q/A$. Velocity defined this way is usually used in specifications for two-phase pipeline conveyors and in the literature. In fact, it is not the actual velocity of either the fluid or the solid, but for the sake of convention, it is used in this way in this guide.

Velocity, Saltation - Particle velocity in two-phase flow at which particles pass back and forth between entrained and sliding flow. During saltation, solids are concentrated in the bottom part of the pipe. At less than the saltation velocity, the particles settle out of the fluid stream.

Velocity, Starting - Fluid velocity through a pipeline required for the fluid stream to entrain a given type of particulate from rest at the bottom of the pipe. The starting velocity is determined empirically.

Vibrator - Device used to enhance ash flow. It may be an internal unit or an external one attached to the outside shell of the ash hopper or tank. The former is usually a vibrating divider baffle plate that bisects the hopper.

Volume Concentration - The ratio of the volume of solid particles to the total volume of a two-phase mixture. A measure of concentration.

Water Seal - Provides a pressure seal between parts having differential movements that do not allow the use of solid seals. Usually a column of water formed by a plate that extends into a water trough.

Water Venturi - See Jet Pump.

Weight Concentration - The ratio of the weight of solids to the weight of the total two-phase mixture. A measure of concentration.

2.2 Acronyms

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BHN	Brinell Hardness Number
DFC	Dry Flight Conveyor
EPRI	Electric Power Research Institute
FMAC	Fossil Maintenance Applications Center
HDPE	High-Density Polyethylene
MBAS	Mechanical Bottom Ash System (same as SSC)
MCR	Maximum Continuous Rating (of a boiler)
MTBF	Mean Time Between Failure
NEM	National Electric Manufacturers Association
PDM	Predictive Maintenance
SCC	Submerged Chain Conveyor
SDCC	Submerged Drag Chain Conveyor
SSC	Submerged Scraper Conveyor (same as MBAS)

2.3 Notations and Abbreviations

A	area
acfm	actual cubic feet per minute
C_D	coefficient of drag
C_v	volumetric concentration
C_w	weight concentration
ΔP	pressure drop

H	head, usually feet or meters
L	length
P	pressure
Q	fluid flow rate
Re	Reynolds number
scfm	standard cubic feet per minute
Sm	specific gravity of the mixture
S_p	specific gravity of the particle
T	temperature
TEL	total equivalent length
Tph	tons per hour
V	velocity
Vf	fluid velocity
Vm	mixture velocity
Vp	particle velocity
Vs	slip velocity
Vt	terminal velocity
w	flow rate of solids

3
TECHNICAL DESCRIPTIONS

3.1 Basic Equipment

The first part of this section describes the detailed design and construction features of the components used in ash handling systems. Where possible and/or appropriate, the different types of components are compared.

3.1.1 Pulverized Bottom Ash Hoppers

The most common boiler bottom design is a water-impounded bottom ash hopper, which provides the following: a means of continuous removal of ash from the furnace, temporary storage of ash, and a means of transporting ash away from the steam generator.

Key Technical Point

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Each of these aspects is described more fully in this section, together with construction of bottom ash hoppers.

The primary function of a hopper is to receive and temporarily store bottom ash that has fallen from the combustion area of the furnace. Therefore, it is designed, in part, on the basis of volumetric considerations. A bottom ash hopper should store, as a minimum, the amount of ash that is produced at Maximum Continuous Rating (MCR) during an 8-hour shift, with some extra capacity for safety.

Key Technical Point

A bottom ash hopper should store, as a minimum, the amount of ash that is produced at Maximum Continuous Rating (MCR) during an 8-hour shift, with some extra capacity for safety.

This sizing should be based on “worst fuel” criteria, meaning the worst coal that might be used from the standpoint of low heating value and/or high ash content, which would result in the most ash needing to be processed by the system. It might seem that the more excess capacity the better, but this is not so. Because the length and width of the hopper are essentially fixed by the boiler outlet dimensions, the only variable is hopper height. This can be increased in only two ways: by excavating a pit under the boiler (which is not desirable) or by raising the entire boiler structure to fit a hopper of the required height beneath it. Either course of action affects the system and increases the cost of the boiler.

In addition to the material problems of providing a deep hopper, there are also operational problems involved in removing clinkerous ash that is piled high. An optimum storage capacity of the bottom ash tank is in the range of 10 to 12 boiler hours (36 to 43 Ksec) output, with storage capacity for 14 hours (50 Ksec) output considered a practical maximum.

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Periodic “deslagging” of boilers has become a more common practice, especially with the conversion of many boilers to burn inexpensive coals that tend to increase slag accumulations on the wall tubes. Usually performed during periods of reduced electricity demand, deslagging is accomplished by dropping boiler load relatively quickly, which initiates a thermal cycle of the boiler tubes and sheds accumulated slag and ash. To ensure that adequate capacity is available in the ash hoppers for this temporary surge in shed material, a complete bottom ash conveying cycle should be performed shortly before and after commencement of deslagging. All but the smallest ash hoppers should be constructed of steel plate at least 3/8 inches (9.5 mm) thick, reinforced and braced to contain a mixture of ash and water at a density of 100 to120 lb/ft^3 (1,602 to 1,922 Kg/m^3).

Key Technical Point

All but the smallest ash hoppers should be constructed of steel plate at least 3/8 inches (9.5 mm) thick, reinforced and braced to contain a mixture of ash and water at a density of 100 to 120 lb/ft^3 (1,602 to 1,922 Kg/m^3).

In addition to this normal loading, columns, supports, and braces should be designed with some allowance for the impact of slag falls, which occasionally occur. The standard plate material used for bottom ash hoppers and accessories is ASTM A-36 carbon steel, with selective upgrading to stainless steel (type 304, 316, or 316L) as a function of exposure to boiler gases, sulfur content of the coal, and accessibility of the part for repair or replacement.

Key O&M Cost Point

The standard plate material used for bottom ash hoppers and accessories is ASTM A-36 carbon steel, with selective upgrading to stainless steel (type 304, 316, or 316L) as a function of exposure to boiler gases, sulfur content of the coal, and accessibility of the part for repair or replacement.

For example, the vertical lifting door enclosures are only occasionally exposed to boiler gas and can be readily “patched up” or even replaced while the unit is on-line; therefore, they are almost always furnished in carbon steel. The inner surface of the seal trough, conversely, is always exposed to boiler gas, has a wet-to-dry interface, is not accessible, and cannot be repaired or replaced without shutting down the unit. Therefore, the seal trough (or at least parts of it) is usually furnished in stainless steel. This same logic extends to overflow boxes, weir boxes, supply and drain piping, and discharge door compartments.

Lining of Bottom Ash Hoppers

To protect the steel plate of the hopper from corrosion, abrasion, impact, and the effects of high temperature, the inside of the hopper is lined with refractory material. The inside vertical walls are lined with either poured or gunnited refractory cement. The sloped hopper sides are lined with the same material or with vitrified paving bricks set on a concrete fill. Use a combined thickness of 9 inches (228 mm) of refractory or brick and cement to line the sloped hopper sides.

Key Technical Point

Use a combined thickness of 9 inches (228 mm) of refractory or brick and cement to line the sloped hopper sides.

If paving brick is used, the mortar joints may fail, allowing the brick to be lifted out of place. Once this condition begins, it rapidly accelerates, resulting in a loss of refractory protection and possibly leading to damage to the crusher by the paving bricks. For this reason, the exclusive use of monolithic refractory has been gaining favor over paving brick, although paving brick has greater resistance to sliding abrasion. In some applications, the sloped hopper bottoms have been successfully retrofit with a layer of stainless steel over the refractory to reduce sliding friction and facilitate the movement of ash to the sluice gate.

Whether cast or gunnited, the hopper refractory is applied over a system of anchors welded to the inside surface of the hopper side plates. Stainless steel and carbon steel anchors are available, although stainless steel is rarely justified in this case. The most important consideration is the spacing of the anchors. The system of anchors welded to the inside surface of the hopper side plates to hold hopper refractory must have a minimum (vertical and horizontal) placement of 15-inch (331-mm) centers.

Key Technical Point

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To prevent refractory failure due to differential expansion between the refractory and the hopper plate, the inside surface of the steel plate should be painted with two coats of bitumastic asphalt before the refractory is applied. This effectively connects the refractory to the anchor system for support and reinforcement but separates the refractory from the hopper steel.

Refractory Cooling

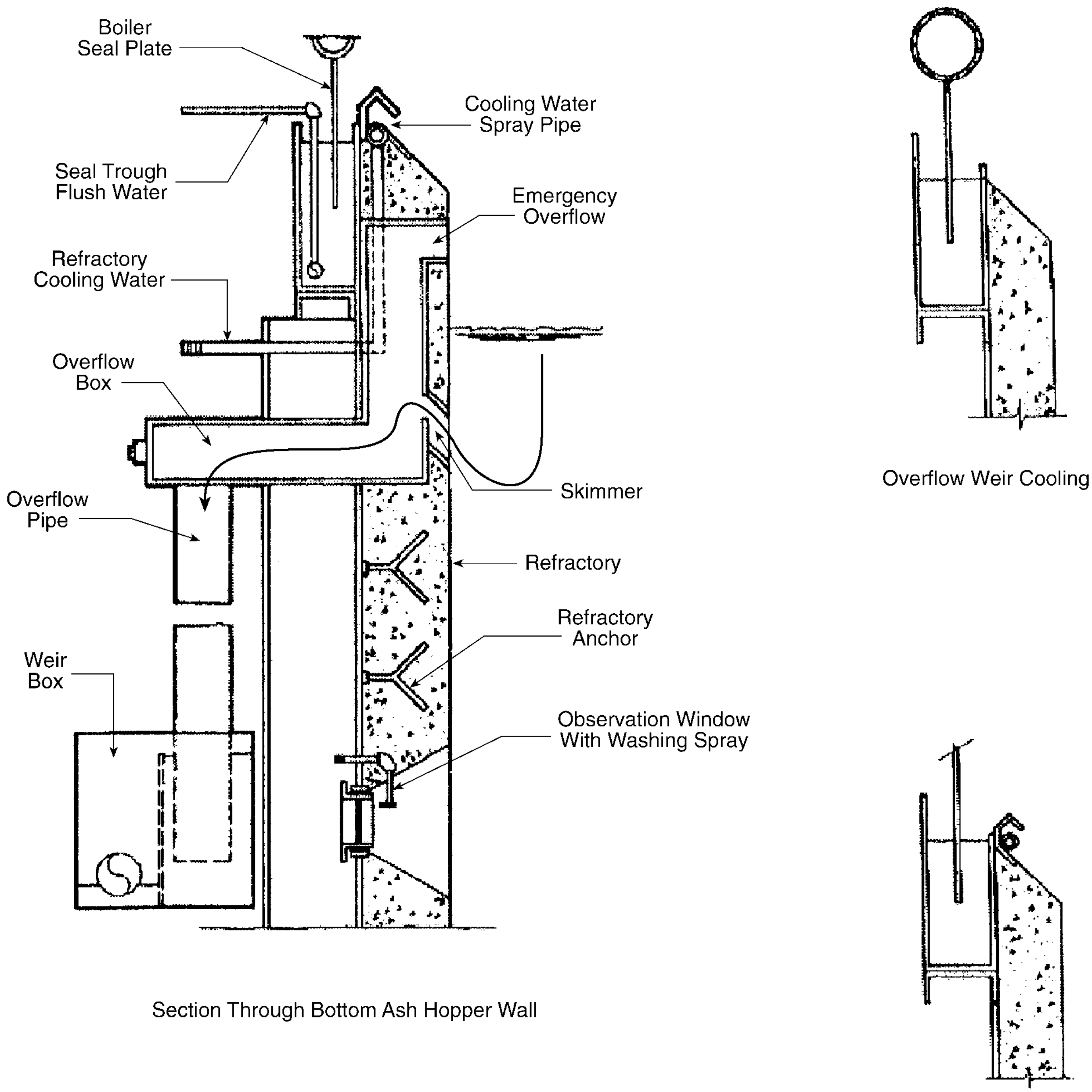
Because refractory cement is exposed to heating by the high-temperature boiler gases and radiant heat through the boiler throat, it would have a short life (especially at the water line) if it were not protected. Protection for the cement is provided by a curtain of cooling water, which is introduced at the top of the refractory cement and cascades down the vertical refractory wall to provide the required cooling and heat absorption.

The two usual means of introducing this refractory cooling water are through a notched weir plate or through a supply pipe with punched holes punched (see Figure 3-1). A water source is located at the top of the refractory wall and supplied with cooling water at the rate of approximately 2 gpm per linear foot (126 ml/sec per 300 mm) to protect the refractory cement from overheating.

Key Technical Point

A water source is located at the top of the refractory wall and supplied with cooling water at the rate of approximately 2 gpm per linear foot (126 ml/sec per 300 mm) to protect the refractory cement from overheating.

The notched weir receives water from a seal trough, from which water overflows into the hopper. The notched weir is sensitive to level installation and can be blocked in places by ash, which interrupts the flow of water at the point of blockage and reduces refractory protection. The pipe-and-deflector method is more resistant to ash fouling, and because the water inside the pipe is under pressure, the uniform flow of water is unaffected by “out of level” installation. The punched pipe is manufactured in segments 10 to 12 feet (3 to 3.6 m) long, each with an individual supply line. Therefore, the punched pipe cooling water supply is preferable and should be specified. All vendors of ash hoppers can provide the punched pipe, even those who consider the notched weir system to be standard.



Punched Pipe Cooling

Figure 3-1
Bottom Ash Hopper Details
Courtesy of United Conveyor Corp.

Figure 3-1 also illustrates the way that sealing is accomplished against air infiltration or exfiltration of boiler gas. A seal plate is fixed to the boiler tube header around the boiler outlet and extends downward into a trough of water around the periphery of the water-impounded ash hopper. The seal plate, which is furnished as part of the boiler, moves upward and downward as the boiler expands and contracts while the seal trough attached to the floor-support hopper remains stationary.

Note: For completeness, the overflow box, cooling water supply piping, and seal trough overflow are all shown in Figure 3-1. In actual practice, these would not be located in the same plane.

To ensure that the seal provided by the water in the trough is not lost by evaporation, a constant supply is piped into the trough and allowed to overflow. This supply of water is introduced at several points in the trough through nozzles oriented to provide flow around the trough.

Because bottom ash particles inevitably get into the seal trough, the trough must be periodically flushed to remove the accumulated sediment. To do this, both a normally closed flushing water supply valve and normally closed drain valves are opened. A flow three times the normal trough makeup flow is required to sweep accumulated sediment from the bottom ash tank seal trough.

Key Technical Point

A flow three times the normal trough makeup flow is required to sweep accumulated sediment from the bottom ash tank seal trough.

The increased flow must be carefully calculated to exceed the drain rate to ensure that the water seal is not lost. Because flushing sediment from the seal trough is very important, this operation should not be left to chance or depend on memory. This function should be automated, even for manual or remote-manual systems. Bottom ash tank seal troughs should be flushed at the end of each conveying cycle at a minimum of once per day to prevent sediment buildup.

Key Technical Point

Bottom ash tank seal troughs should be flushed at the end of each conveying cycle at a minimum of once per day to prevent sediment buildup.

Only fresh water, not salt or brackish water, should be used for flushing seal troughs and hopper cooling.

The bottom ash hopper must have a pool of water, which causes falling slag to shatter. The slag thus becomes easier to discharge and dispose of properly. This shattering and disintegration is due to thermal shock and is most effective if the impounded water temperature does not exceed 140ºF (80°C).

Overflows, Bottom Ash Hoppers

Provision must be made for the overflow of the ash hopper cooling water; at the same time, the floating ash must be removed, and the water seal must be maintained. This function is performed by weir skimmers, as shown in Figure 3-2.

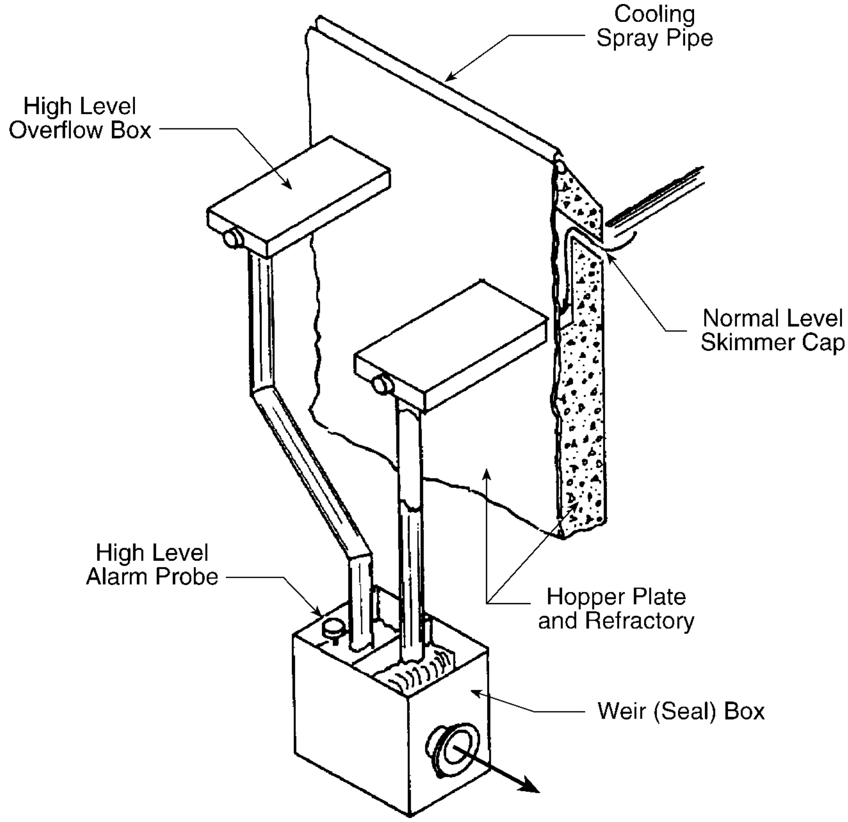


Figure 3-2
Bottom Ash Hopper Overflow Details
Courtesy of United Conveyor Corp.

Ordinarily, each hopper has at least two skimmers: one at the normal water level and a second that is an emergency overflow at a level approximately 6 inches (152 mm) higher, if the normal-level skimmer becomes plugged. For large hoppers, the skimmers are either made wider or multiple skimmers are used. Water from the skimmer caps is piped to a compartmented overflow weir box placed at or near the base of the hopper. This overflow provides a water seal to prevent boiler gases from escaping.

Typical weir box construction is shown in Figure 3-2. It is desirable to have the normal and emergency overflows piped to separate compartments in the weir box. The emergency overflow compartment can then be fitted with a water detector to provide an alarm if the overflow comes from the emergency skimmer, which indicates that the normal-level skimmer is plugged.

Hopper Discharge Doors

In the standard water-impounded bottom ash hopper, the discharge doors are fitted to either the front or a side face of each compartment, depending on the standards of the vendor. Either arrangement is satisfactory. One or the other may be more adaptable to the required pipe routing, but this should certainly not be the basis for selecting the system supplier. The discharge doors are placed inside watertight enclosures, which also support the crushers and allow observation of and access to the doors. Figure 3-3 shows the layout of a typical hopper discharge door.

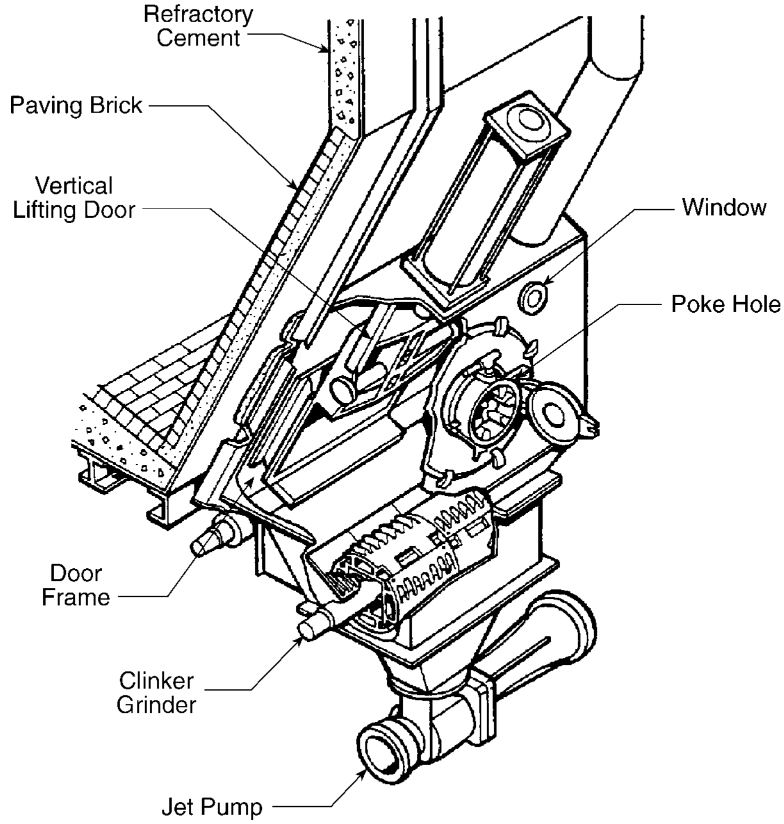


Figure 3-3
Bottom Ash Hopper Discharge Door, Enclosure, and Accessories
Courtesy of United Conveyor Corp.

Discharge doors are available in a number of opening sizes. The advantages of a larger door opening are largely lost, however, if the size of the crusher is not increased. Generally, the basic 2-ft x 2-ft (0.61-m x 0.61-m) door is adequate for most applications unless the designer knows in advance that slagging and/or oversized slag falls can be expected. The engineer should also consider the materials of construction. Stainless steel is available for the most critical wetted parts (where corrosive conditions are expected), and rubber is available as a gate face for better sealing and closure. The engineer should be assured that the discharge door is designed so that the gate seat and face are not in contact while the gate is being positioned but that they are tightly wedged together when the gate is closed. The watertight enclosures placed around the discharge doors should be fabricated from plate at least 3/8 inch (9.5 mm) thick to ensure reliability and strength.

Key Technical Point

The watertight enclosures placed around the discharge doors should be fabricated from plate at least 3/8 inch (9.5 mm) thick to ensure reliability and strength.

Carbon steel is usually adequate because of the accessibility of the enclosures for patching and repair, but stainless steel construction can be specified wherever warranted.

As a minimum, the discharge door enclosures should be equipped with the following:

- Waterproof flood light
- Observation window(s)
- Pressurized access door(s)
- Pressure- and vacuum-relief valves
- Dilution water spray
- Manual jetting nozzle

Pressurized Access Doors (Poke Holes)

Although the vast majority of applications are on balanced-draft units, the pressurized or aspirated poke hole is recommended for maximum operator safety in the event that a boiler puff or transient occurs while an operator is using the observation door or poke hole.

Key Human Performance Point

Although the vast majority of applications are on balanced-draft units, the pressurized or aspirated poke hole is recommended for maximum operator safety in the event that a boiler puff or transient occurs while an operator is using the observation door or poke hole.

This arrangement ensures that the resulting flow is composed of ambient air into the boiler instead of boiler gases out of it—if the poke hole is opened for visual or rodding access. Note that a pressurized poke hole seals only the outflow of gases, not water. A poke hole should never be opened unless it is located above the hopper water level.

A poke hole is shaped like a venturi, with a compressed air manifold oriented so that airflow is induced into the boiler. For additional safety, the door should be mechanically interlocked so that it cannot be opened unless the compressed air valve is opened. Another safety feature worth considering is a local pressure gauge on the aspirating air supply. This allows confirmation of adequate supply pressure before the poke hole is opened. A poke hole should be opened very slowly to ensure that no boiler gasses flow out.

Because the aspirated poke hole uses a significant amount of plant air, it is important to provide for an adequate supply. Flow rates in the range of 250 to 500 scfm (117.9 l/s to 234 l/s) at 80 psi (50 kPa) are not uncommon.

Pressure- and Vacuum-Relief Valves

While the ash system pump is operating (whether jet pump or mechanical pump), the door enclosure is subject to significant negative pressure if the discharge door is closed or blocked. Conversely, if the discharge door is closed and the sluice line becomes plugged or blocked, the door enclosure is subjected to positive pressure. To safeguard against either case, each door enclosure should be fitted with pressure-relief and vacuum-relief valves. The pressure- and vacuum-relief valves of the door enclosure must be automated so that their purpose of protecting the equipment and personnel cannot be defeated or manipulated.

Key Technical Point

The pressure- and vacuum-relief valves of the door enclosure must be automated so that their purpose of protecting the equipment and personnel cannot be defeated or manipulated.

Serious injuries have occurred as a consequence of having relief valves that could be defeated by an operator.

Dilution Pipe

A dilution-spray pipe should be placed near the enclosure outlet. This is necessary whenever 1) the bottom ash hopper is full of ash and 2) the ash that comes out of the door is very concentrated. In this concentrated condition, the ash overloads the jet pump, which tries to clear itself with nozzle water as described earlier in this section. The net result is a very slow feed of ash into the pipeline. The dilution pipe adds enough water, usually about 100 gpm (6.3 l/s), to increase the rate of transport.

Emergency Jetting Nozzles

The door enclosure should also be fitted with a manual nozzle aimed through the center of the discharge door for emergency jetting. This is used to dislodge and move ash or clinkers that become stuck in the door opening. In many instances, it eliminates the need for drawing down the water level in the hopper and lancing the material.

Dual-Discharge Equipment

Discharge doors can be placed on both (opposite) sides of each hopper compartment to increase redundancy of installed equipment. For example, with dual-discharge equipment, there would be no time constraint on repairing or replacing either a crusher or an ash pump. In addition, if each set of discharge doors has its own sluice pipe to the disposal point, the ash removal rate can be doubled (as long as sufficient water supply and pump capacity are available). Dual-discharge equipment is a conservative but costly approach and is generally specified only by power plants that have experienced such operational difficulties to justify the added expense. Dual-discharge equipment may also be justifiable if there is a possibility of switching to a fuel that is higher in ash content or lower in heating value.

Jetting Nozzles

Flushing nozzles should be mounted on the slopes of a hopper to flush the ash to the bottom of the hopper and out through the discharge door. The maximum effective distance of a slope nozzle from the hopper discharge is generally 13–15 feet (4– 4.6 m); if the slope length to the hopper outlet exceeds this measurement, two banks of nozzles should be used.

Key Technical Point

The maximum effective distance of a slope nozzle from the hopper discharge is generally 13–15 feet (4–4.6 m); if the slope length to the hopper outlet exceeds this measurement, two banks of nozzles should be used.

The first bank is located at the top of the slope and the second approximately halfway down. The nozzles in each bank should be spaced approximately 2 feet (0.6 m) apart. Thus, the total number of nozzles in each bank is a function of the hopper width (typically four or six nozzles). Typical nozzle water requirements are 70 to 100 gpm (4.41 to 6.3 l/s) each, depending on the vendor—at a pressure of 100 psi (690 kPa). Higher pressures are not recommended because the water stream then rat holes through the impounded ash rather than moving it down the slope. For ease of maintenance, nozzle holders should be designed so that they can be withdrawn from outside the hopper (although the unit must be shut down and the hopper water drained to allow withdrawal of the nozzles).

Rear Door Nozzles

While slope nozzles help to move ash downward toward the discharge doors, the converging geometry of the bottom of the compartment can cause packing and arching of the ash. To guard against this condition, a pair of nozzles is placed on the walls opposite the rear door and aimed through the opening. The door nozzles are usually activated just before opening the discharge door to agitate and dilute the compacted ash at the bottom of the hopper. They normally operate during the entire cycle of pulling ash from that particular compartment but can be turned off if necessary to conserve water.

3.1.2 Slag Tanks

For continuously slagging wet-bottom boilers, slag tanks are applied (see Figure 3-4). Slag enters the tank through a throat section, which is hung from the boiler. Near the top of the throat, a water-cooled arm is sometimes used, which swings back and forth periodically to cut off any strings of chilled slag that may accumulate near the point of discharge. The slag then drops into a pool of water where agitating jets assist in the granulation process. A trough around the upper periphery of the throat admits a curtain of water down the sides of the throat lining to prevent slag from sticking to it. A water seal trough is provided between the throat and the slag tank to permit movement of the throat due to boiler expansion. To maintain the low temperatures required for quenching and shattering slag, a slag tank system requires considerably higher makeup water flow than impounded water bottom ash hoppers. Feeding of slag from the tank into a crusher and pump suction connection is similar to that described above for an ash hopper under a dry-bottom boiler.

Slag tanks (and their subcomponents) are functionally analogous to the bottom ash hoppers described in detail earlier in this section. Because the bottom ash emptying, transport, and disposal systems downstream of both types of boiler bottoms are identical, no further differentiation between the two boiler bottom types will be made in this guide.

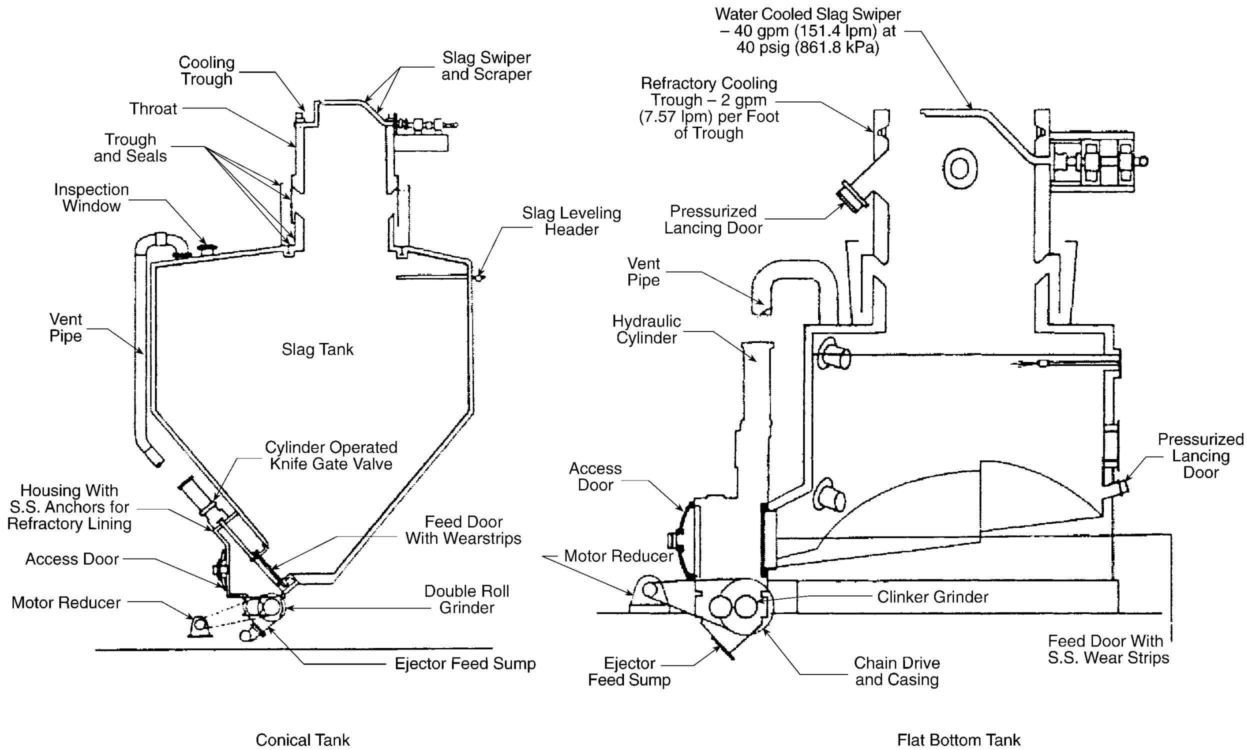


Figure 3-4
Typical Slag Tanks
Courtesy of Allen-Sherman-Hoff

3.1.3 Crushers

On hydraulic pipeline ash conveyors, it is important that the maximum dimension of the ash (or slag) not exceed one-half the inside diameter of either the pipe or the internal pump clearance to ensure that the ash (slag) can be reliably transported without bridging or plugging.

Key Technical Point

On hydraulic pipeline ash conveyors, it is important that the maximum dimension of the ash (or slag) not exceed one-half the inside diameter of either the pipe or the internal pump clearance to ensure that the ash (slag) can be reliably transported without bridging or plugging.

Ash and slag are reduced to these dimensions by crushers. The two principal types of crushers are classified by the number of rotating elements, that is, single-roll crushers and double-roll crushers. Single-roll crushers reduce using a combination of impact, shear, and compression methods. Bottom ash, although hard and abrasive, is usually friable—a property that a properly designed single-roll crusher uses to advantage. The crusher splits or shears the ash between the single roll and an anvil (see Figure 3-5). Double-roll crushers reduce primarily through compression. As shown in Figure 3-6, the double-roll crusher uses a gear set and compresses the ash into the clearance between the counter-rotating rolls. Less friable ash and slag may be processed more effectively by a double-roll crusher.

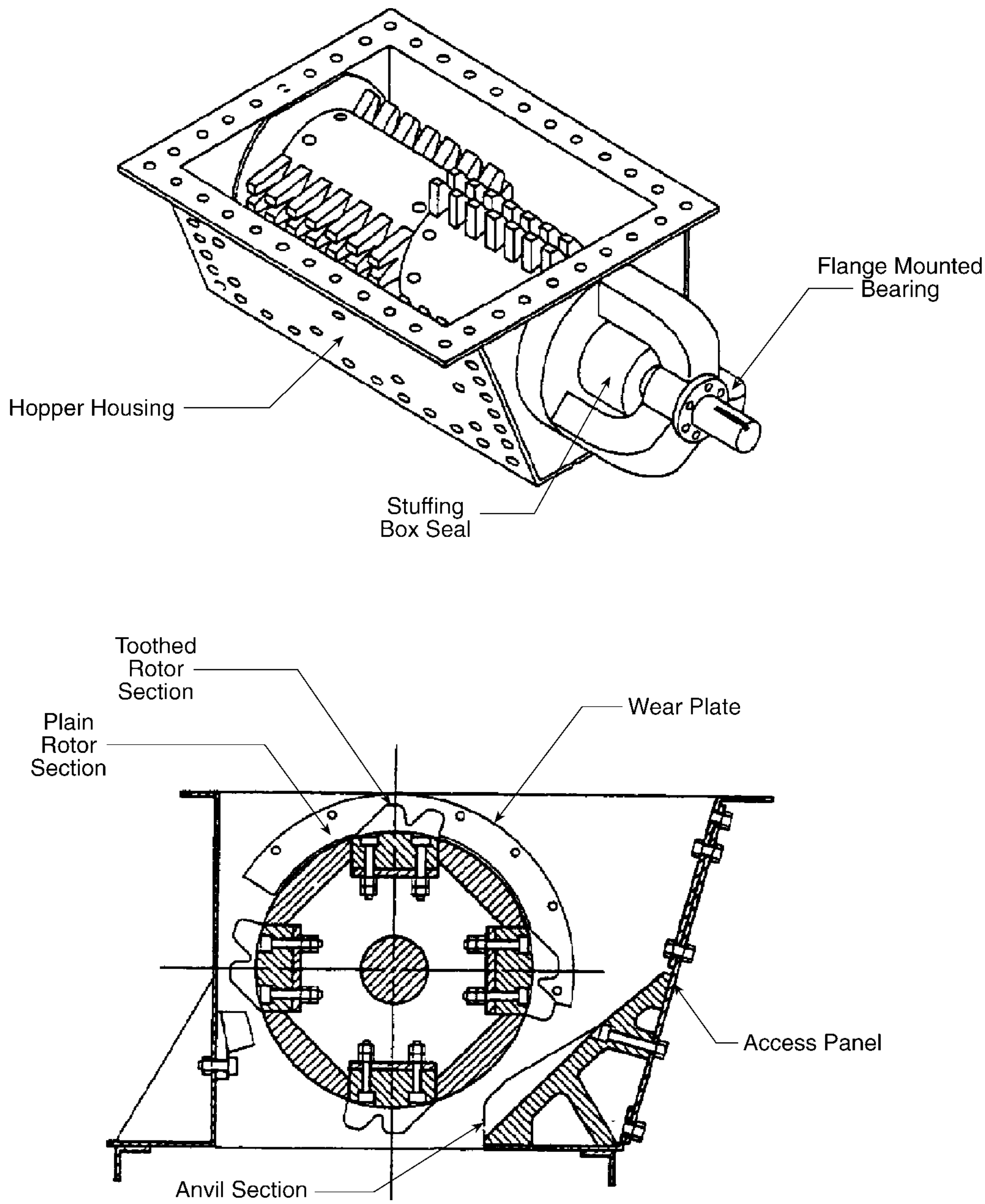


Figure 3-5
Single-Roll Crusher
Courtesy of Combustion Engineering Co.

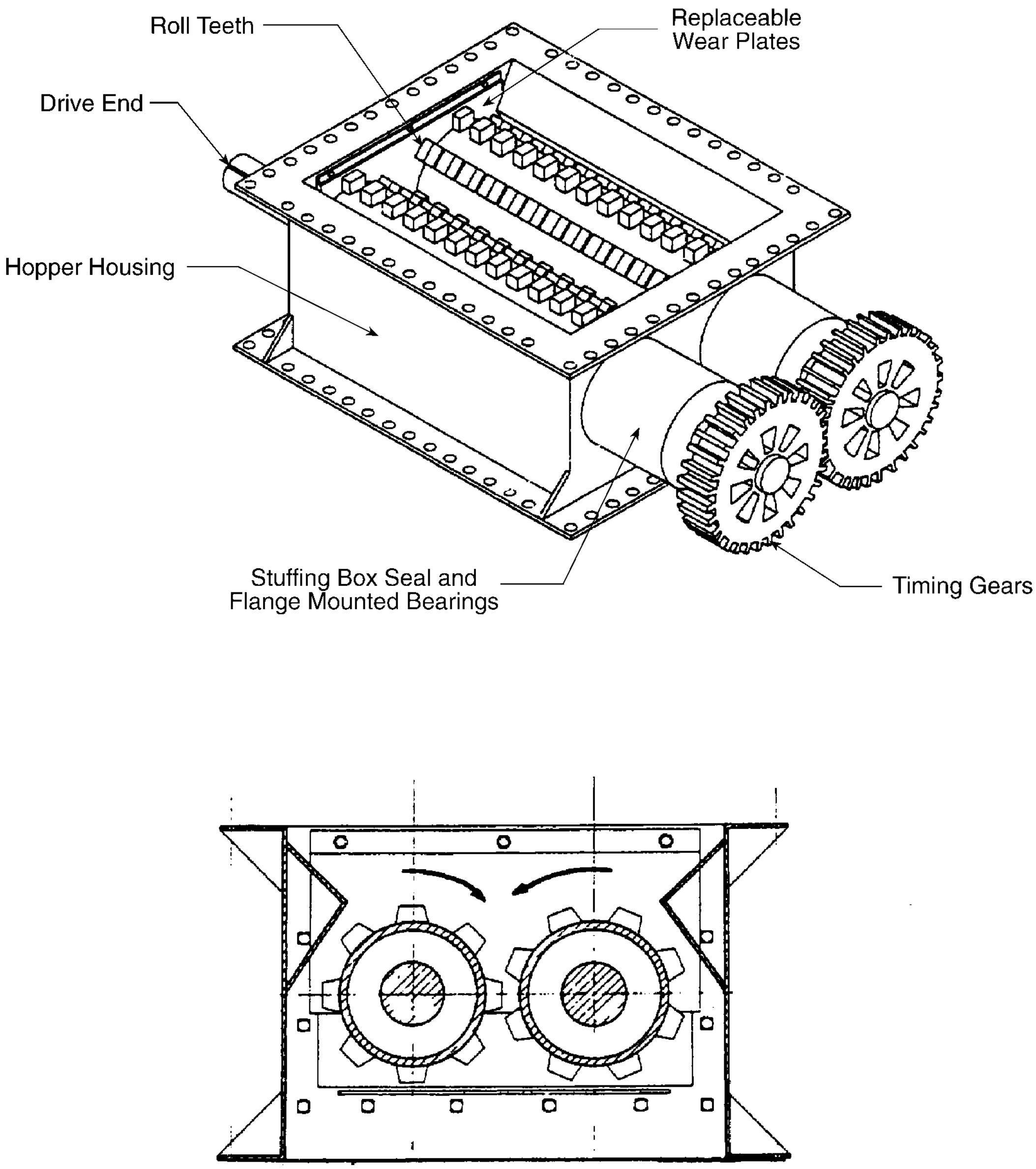


Figure 3-6
Double-Roll Crusher
Courtesy of Allen-Sherman-Hoff

A well-designed crusher should have sufficient space below the high points of the roll to allow a clinker to fall into the low spaces, so that the next high segment of the roll gets a good bite on the clinker. Regularly spaced knobs on double-roll crushers can result in the clinker "walking" around on top of the rolls to ensure that it is not processed too quickly.

Other important design features in a crusher include the bearing type, rotor design, and ease of access for repair and replacement of all wear parts. Manufacturer's drawings and cut sheets should be carefully studied during the consideration or evaluation of proposals to assess their suitability by these criteria. Several manufacturers offer symmetrical (and reversible) roll segments and wear liners. Reversing the roll segments and wear liners of the crusher at their half-life will extend the interval between crusher rebuilds.

Key Technical Point

Reversing the roll segments and wear liners of the crusher at their half-life will extend the interval between crusher rebuilds.

To prevent ash from getting into the shaft seals or packing glands, some major ash system vendors pipe seal water to the shaft seals; thus, the flow consists of clean water into the crusher hopper rather than ash-laden water out of it. Significant usage of filtered water at rates of 5 to 25 gpm (0.32 to 1.5 l/s) while conveying is required to keep the seal air clear of ash.

Key Technical Point

Significant usage of filtered water at rates of 5 to 25 gpm (0.32 to 1.5 l/s) while conveying is required to keep the seal air clear of ash.

Therefore, the evaluating engineer should determine each vendor's requirements for this water. Recent innovations in packing systems allow some shafts to be sealed without the use of flush water. In these cases, grease is used in lieu of water. The grease can be applied either by local feeders or as part of an automatic lubrication system.

Shaft leakage is typically caused by shaft deflection, improper protection of packing material against the abrasive slurry, or lack of lubrication of packing material. A floating type seal can be used to combat this. An outer diaphragm on each end of the shaft allows movement but keeps the seal arrangement intact (see Figure 3-7).

Information on a potential alternative mechanical seal for the crusher is supplied in Appendix B.

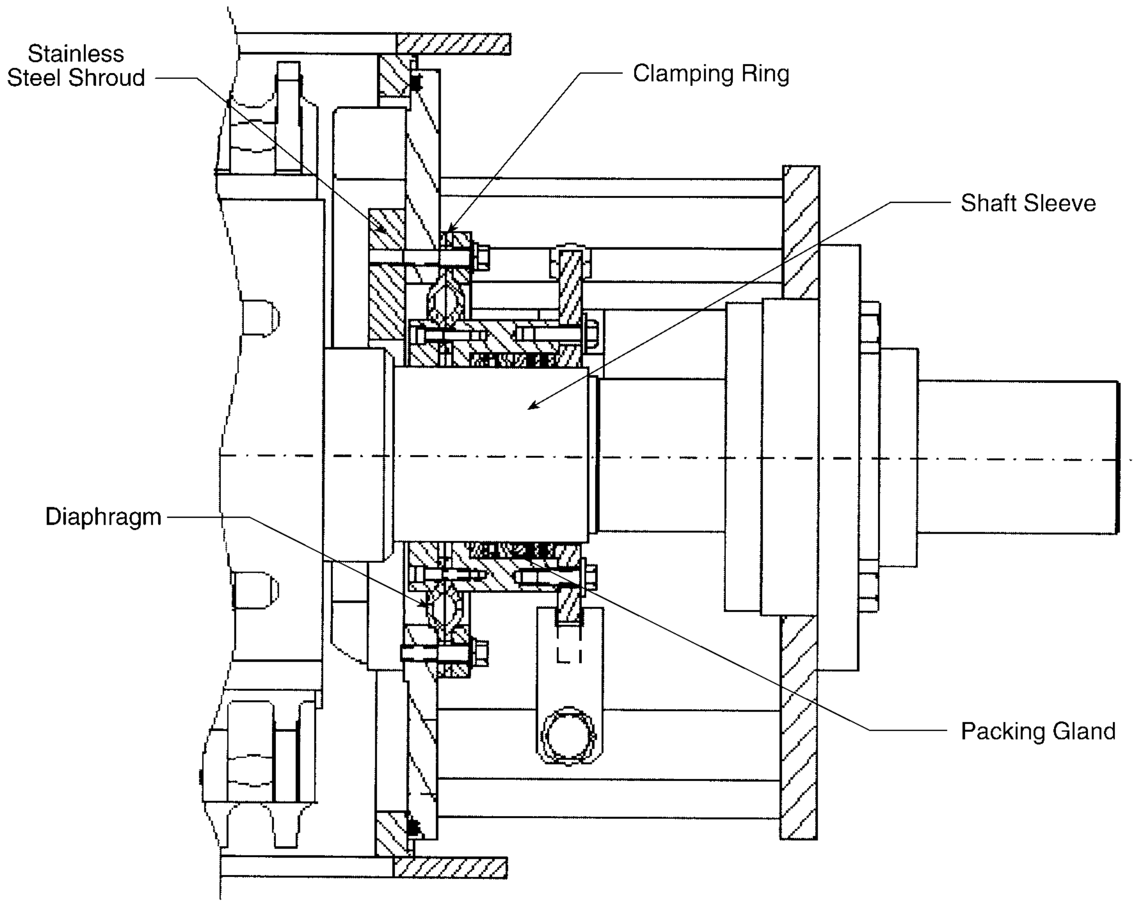


Figure 3-7
Floating Seal Arrangement
Courtesy of United Conveyor Corp.

3.1.4 Ash Pumps

After crushing, ash is fed into an adapter or sump from which it flows into some form of pumping device. The pump may be an ejector (jet pump) or a centrifugal slurry pump. Figure 3-8 illustrates a jet pump, and Figure 3-9 shows a cross-section through a typical water-sealed centrifugal pump.

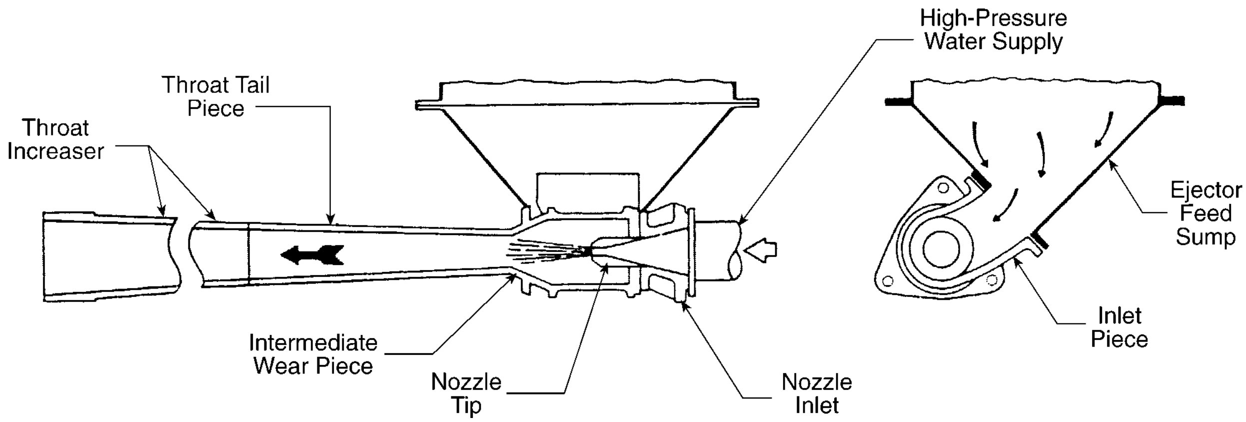


Figure 3-8
Typical Ejector
Courtesy of Allen-Sherman-Hoff

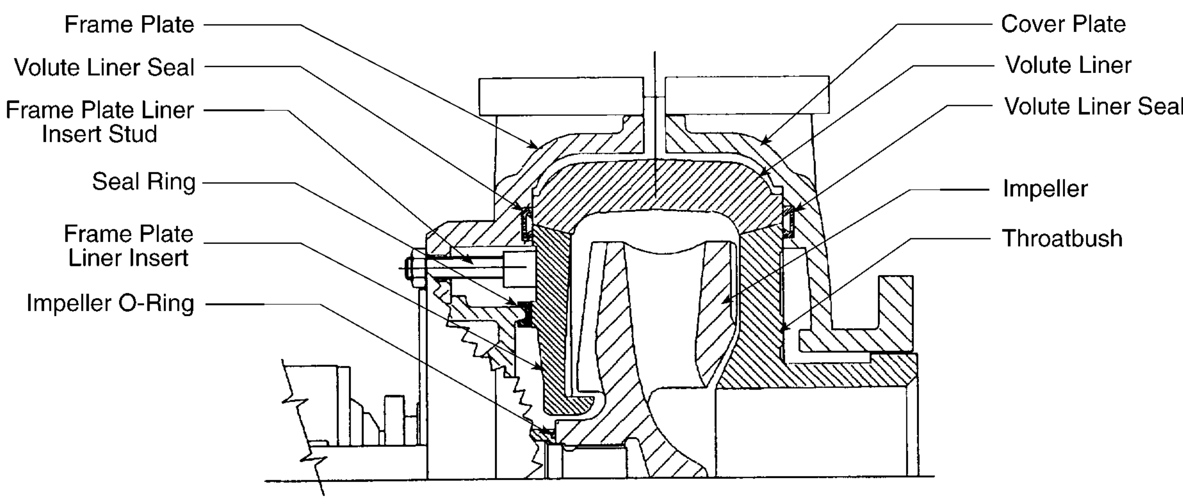


Figure 3-9
Centrifugal Ash Pump Assembly
Courtesy of Warman, International

In applying either pump, dilution is required to provide slurry that can be pumped. Usually the solids represent about 20% of the total weight of the slurry pumped. The suction of an ejector is limited by the system back pressure (head), which also determines the amount and pressure of the ejector impulse water.

When a jet pump operates, high-pressure water is delivered through the nozzle to create a vacuum. Water or ash/water slurry is drawn into the inlet, and the combined total is discharged through the outlet. The amount of mixture drawn into the inlet is inversely proportional to the discharge pressure. This unique feature of the jet pump is known as *self-regulation*. Self-regulation dilutes the slurry mixture and helps prevent pluggage.

> **Key Technical Point**
>
> **This unique feature of the jet pump is known as *self-regulation*. Self-regulation dilutes the slurry mixture and helps prevent pluggage.**

If an extremely dense mixture of ash and water is fed into a jet pump (and conveyor line), the amount of additional mixture admitted is reduced if the nozzle water supply is fixed. This dilutes the mixture and helps prevent plugging. When the system pressure drops as a result of the dilution, additional quantities of ash and water can be pulled through the inlet. The minimum acceptable amount of nozzle supply water required to properly convey the ash equals 75% of the minimum design flow through the pipe.

> **Key Technical Point**
>
> **The minimum acceptable amount of nozzle supply water required to properly convey the ash equals 75% of the minimum design flow through the pipe.**

For example, if the minimum velocity of bottom ash slurry is 8 ft/s (2.4 m/s), the corresponding flow through a 10-inch (25.4-cm) pipe is approximately 1,960 gpm (123 l/s). Therefore, the minimum nozzle flow is 75% of 1,960 gpm (123 l/s), or 1,470 gpm (93 l/s).

The 75% flow requirement stems from the fact that slurry that is already moving does not settle out when velocity is reduced to 75% of the minimum design value. Hence, even if the impounded slurry flow from a tank or hopper is cut off, the velocity in the pipe is sufficient (due to the flow of nozzle water) to prevent the solids from settling out and possibly plugging the line.

It is worthwhile to differentiate between a jet pump and another common venturi device, the water-powered exhauster (see Figure 3-10). The principal difference between a bottom ash jet pump and a water-powered exhauster is the water supply nozzles used in each type of equipment. A jet pump is fitted with a single, large-diameter nozzle, whereas an exhauster is fitted with between 12 and 25 small nozzles. Water-powered exhausters are commonly used in hopper emptying and sluicing applications outside of the bottom ash system, such as economizer ash systems.

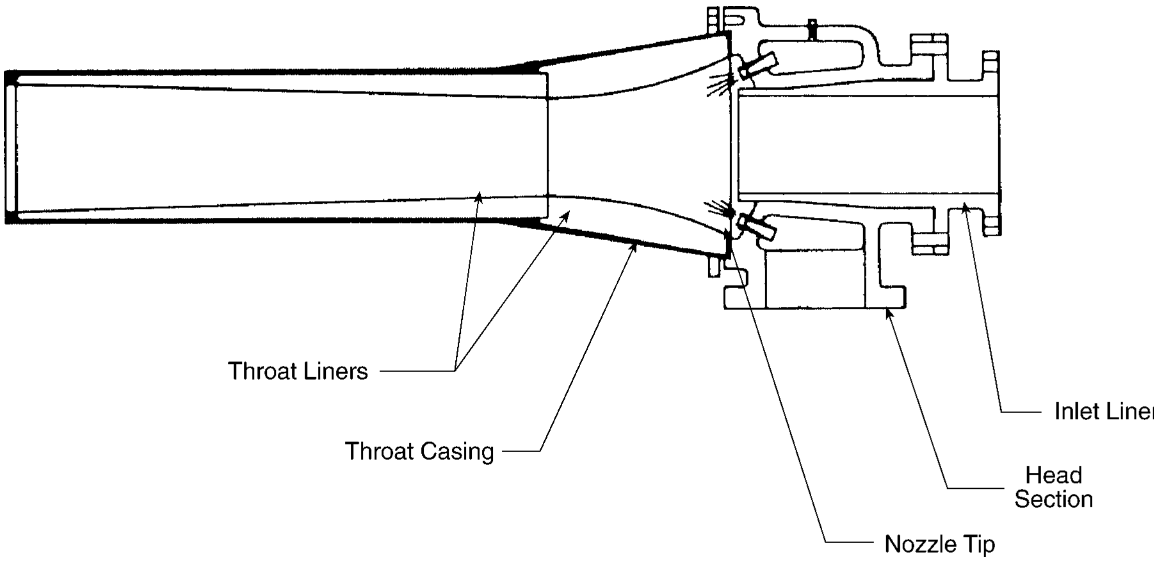


Figure 3-10
Water-Powered Exhauster
Courtesy of Allen-Sherman-Hoff

A centrifugal pump pulls the same amount of slurry through its suction as it delivers to the discharge line. To prevent overloading, a special suction fitting is provided when a pump is directly connected to an ash hopper outlet. Sufficient dilution water must be added at the pump suction to control the specific gravity of the slurry discharged by the pump.

For the same discharge quantity and discharge head, a centrifugal pump is about 40% more efficient than an ejector, without considering the efficiency of auxiliary pumping equipment that supplies the ejector nozzle. Ejectors can be serviced more easily, but such service may be required much more frequently than for a comparable centrifugal pump. In addition, offsetting the ease of maintenance of ejectors is the requirement for maintenance of the high-pressure centrifugal pumps supplying impulse water to the ejectors.

Key O&M Cost Point

Ejectors can be serviced more easily, but such service may be required much more frequently than for a comparable centrifugal pump. In addition, offsetting the ease of maintenance of ejectors is the requirement for maintenance of the high-pressure centrifugal pumps supplying impulse water to the ejectors.

Hard metals are employed in the construction of both types of pumps in areas where abrasion is most severe. Since abrasive wear is more rapid as velocities increase through pumps, it is desirable to maintain velocities as low as possible, as long as efficiency of the pump is not impaired. For ejectors, the velocity through the throat is critical, while in the case of centrifugal pumps, the impeller peripheral (tip) speed is to be kept to a minimum.

When system heads exceed about 150 feet (46 m), ejectors generally are not applicable within reasonable limits for impulse water pressure. Series operation with ejectors is impractical. On the other hand, centrifugal pumps can be conveniently placed in series for high head requirements.

Centrifugal pumps also have an important advantage over ejectors in closed loop recirculating systems. The high pressure usually required by ejector impulse nozzles puts a severe wear condition on the nozzles and on water pumps, which must handle return water from the conveying system. Clarity of recirculated water does not present a wear problem to a centrifugal slurry pump, but a small amount of clean, grit-free gland seal water must be available. If a recirculating system does not have an outside source for this seal water, the system return water supply can be used by bleeding off the required amount and passing it through a self-cleaning filter. This way, no additional water enters to the system. In systems using centrifugal pumps, the return water pumps will be required to deliver the recirculated water at a relatively low pressure compared to ejector requirements. In this case, there will be a significant power savings, and the return water pumps will be subjected to considerably less wear.

3.1.5 Pipe and Fittings

Pipe and fittings used in ash handling systems can be categorized as metallic or nonmetallic. They can be further classified as plain-, beveled-, ring-, or flanged-end. Plain-end pipe is easier and less expensive to produce than other types and, because the exact length required can be cut from stocked full-length sections, it is more readily available.

Key O&M Cost Point

Plain-end pipe is easier and less expensive to produce than other types and, because the exact length required can be cut from stocked full-length sections, it is more readily available.

Exact lengths of other piping types are usually produced only to order but can be fabricated in the field with special tooling and techniques. Only with a well-designed and well-executed support and anchoring system can plain-end pipe can be as satisfactory as the other piping types.

Beveled-end pipe and fittings can make stronger mechanical connections than plain-end ones. This characteristic ensures that pipe movements are accommodated in the expansion joints provided for that purpose. This can be important in hydraulic systems, where there may be pipe stresses due to inertial forces (water hammer).

Ring-end pipe and fittings utilize a coupling design that seals by compressing a gasket into a shoulder provided by a groove or ring at both sides of the joint. Since wear life is so dependent on wall thickness, externally applied rings are used for bottom ash systems.

Flanged-end pipe and fittings utilize a simple flange and face gasket arrangement that provides maximum end pull strength and precise joint alignment. The numerous bolts at each joint add a margin of reliability to the connection but, compared to coupled joints, generally require more time during installation and maintenance activities. Spool piece length must be held to a tight tolerance to allow proper gasket compression without introducing residual stresses.

Metallic Pipe and Fittings (Unlined and Lined)

Unlined metallic piping systems are commonly used and have the advantages of simple construction and maintenance along with low initial cost.

Key O&M Cost Point

Unlined metallic piping systems are commonly used and have the advantages of simple construction and maintenance along with low initial cost.

Common materials include carbon steel and various alloys of cast iron. As the hardness of the alloy increases, so does its wear life and cost. Fittings in this type of system are commonly cast of a harder alloy than the straight lengths to reduce the effects of increased abrasion. Fittings can also be cast with thickened sections, called *wearbacks*, to extend their wear life. Basalt-lined pipe and fittings for hydraulic ash handling systems are an option for higher wear areas that offers gem-like hardness with abrasion resistance. Their disadvantage is their weight and brittleness.

Key Technical Point

Basalt-lined pipe and fittings for hydraulic ash handling systems are an option for higher wear areas that offers gem-like hardness with abrasion resistance. Their disadvantage is their weight and brittleness.

In the manufacturing process, raw quarried basalt is melted and cast (as a molten metal would be) into molds that produce linings and shapes. These shapes are then heat treated to produce a material of gem-like hardness, measuring 7 to 8 on the Mohs scale of material hardness (~650 to 1,000 Brinell hardness number [BHN]). In addition to abrasion resistance resulting from its hardness, basalt is more resistant to acid and alkaline environments than ferrous pipe. The cast and heat-treated liners are grouted or cemented into steel shells to produce pipe and fittings. The quality of the grouting and cementing procedure is of the utmost importance. Even when linings are not worn and still maintain their integrity, the pipe or fitting will have failed if the lining was "washed out" of place.

Although basalt is very hard, it is also heavy and brittle. This requires extra care in handling and extra support for its installation. Basalt-lined pipe fittings and liners cost considerably more than ferrous alloy pipe. They also generally last longer (or handle much more material) before requiring replacement. If corrosion as well as abrasion is a problem, the difference in operating life can be even higher. The lifetime cost of basalt material can often justify the increase in initial cost.

Key O&M Cost Point

The lifetime cost of basalt material can often justify the increase in initial cost.

Plastic Pipe and Fittings

This category of pipe includes polypropylene, high-density polyethylene (HDPE), and ceramic-lined plastic pipe, which are offered for bottom ash slurrying. The main advantages offered by nonferrous HDPE pipe material are ease of installation (due to longer, lighter lengths) and longer life (due in part to its resistance to chemical attack).

Key O&M Cost Point

The main advantages offered by nonferrous HDPE pipe material are ease of installation (due to longer, lighter lengths) and longer life (due in part to its resistance to chemical attack).

At plants burning eastern coal (even low sulfur coal), the ash sluice water can become acidic and attack ferrous pipe and components. This chemical attack forms an oxide on the metallic surfaces. Normally, this oxide would protect against further corrosion. However, when conveying abrasive slurries, the oxide is worn away and new layers of metal are continually exposed to chemical attack. This combined cycle of corrosion-erosion eventually wears out ferrous pipe, although the wear is usually blamed on erosion alone.

Section 4, “Material and Equipment Application Recommendations,” includes a summary of critical parameters and compares a variety of available pipe materials.

Couplings

Frequently, plain-end pipe is connected with general-purpose sleeve-type couplings that rely on the friction force of the gasket material to keep the couplings in place (see Figure 3-11). Extra care must be taken in engineering and constructing a piping system with general-purpose couplings to minimize the possibility of coupling disengagement due to expansion, contraction, or impact forces.

Key Technical Point

Extra care must be taken in engineering and constructing a piping system with general-purpose couplings to minimize the possibility of coupling disengagement due to expansion, contraction, or impact forces.

The possibility of coupling disengagement can be reduced by the use of couplings that utilize a tangential clamping bolt that "locks" the coupling half onto the pipe (see Figure 3-12). This helps to ensure that axial pipeline movements are accommodated by expansion joints rather than by couplings. Locking-type connections for ash lines must be re-torqued after initial operation.

Key Technical Point

Locking-type connections for ash lines must be re-torqued after initial operation.

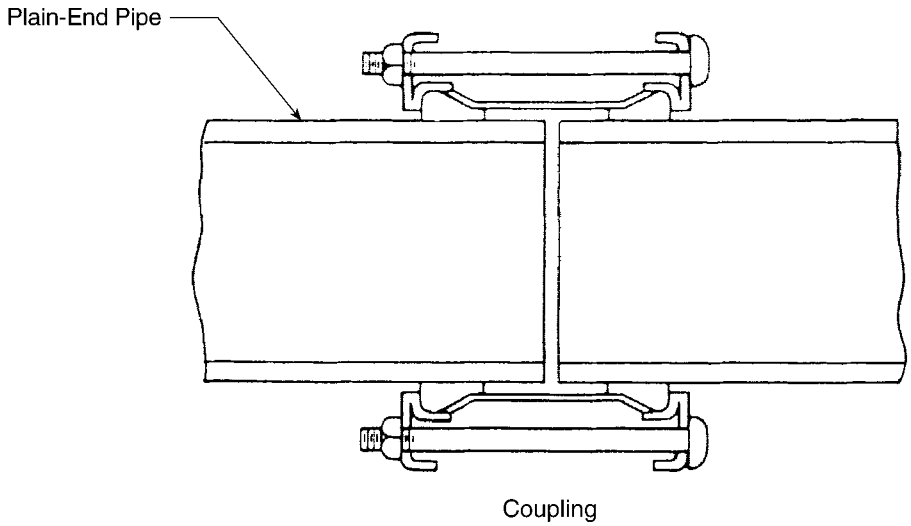


Figure 3-11
Typical Sleeve-Type Coupling
Courtesy of United Conveyor Corp.

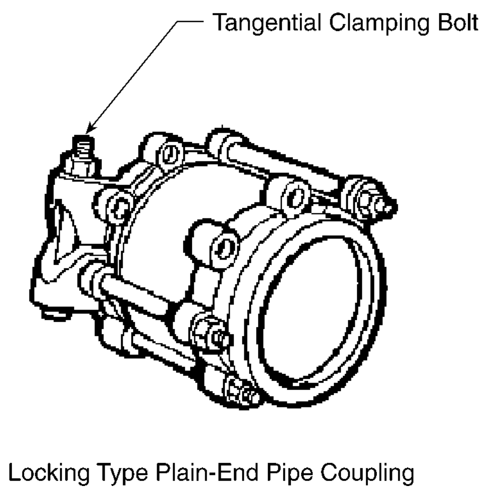


Figure 3-12
Typical Tangential Clamping-Type Coupling
Courtesy of United Conveyor Corp.

Ring-ended pipe is joined with couplings that compress a circumferential gasket into a raised shoulder at each side of the joint. These couplings generally provide a good seal and adequate end-pull strength (see Figure 3-13). (Victaulic® is a registered trademark of Victaulic Company of America.)

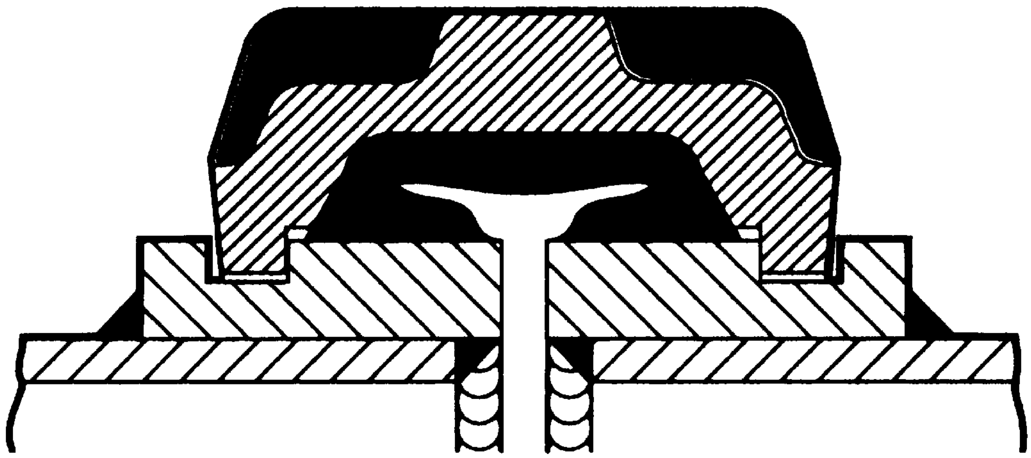


Figure 3-13
Typical Coupling for Ring-Ended Pipe
Courtesy of Victaulic®

Expansion Joints

Although rubber expansion joints are used on air line piping within ash handling systems, the primary types of expansion joints used in conveyor lines are metallic-sleeve and metallic-bellows. Sleeve-type and bellow-type expansion joints each have their own advantages. Sleeve-type expansion joints have lower initial costs and are generally more durable. Bellows-type expansion joints are less likely to leak and require less force to operate, which reduces the size (and cost) of pipe anchors.

Key O&M Cost Point

Sleeve-type and bellow-type expansion joints each have their own advantages. Sleeve-type expansion joints have lower initial costs and are generally more durable. Bellows-type expansion joints are less likely to leak and require less force to operate, which reduces the size (and cost) of pipe anchors.

As a rule, sleeve-type expansion joints require a force of approximately 1,000 lb/in (175 kN/m) of nominal diameter to actuate; bellows expansion joints require only about one-tenth as much force to actuate. Expansion joints in ash systems must be fitted with stops to prevent overexpansion or separation. The stops ensure that the entire pipe movement is shared by all expansion joints.

Key Technical Point

Expansion joints in ash systems must be fitted with stops to prevent overexpansion or separation. The stops ensure that the entire pipe movement is shared by all expansion joints.

Gaskets

The most important requirement for a gasket is that it be fabricated from a material that is suitable for the operating environment. The usual parameter is high temperature. It is usually best to specify the maximum expected temperature and allow the vendor to provide a suitable gasket that meets certain minimum properties when tested in accordance with ASTM test procedures.

3.1.6 Hydraulic Line Gates

Rotary and straight-line slide gates used in hydraulic conveyor lines have configurations similar to pneumatic slide gates (see Figures 3-14 and 3-15). They have (or should have) heavier construction because of the more abrasive nature of bottom ash transporting, which is the usual application for hydraulic conveyors. A greater variety of resilient seating materials is available for hydraulic slide gates, including polyurethane, which provides good service in abrasive and contaminated water environments.

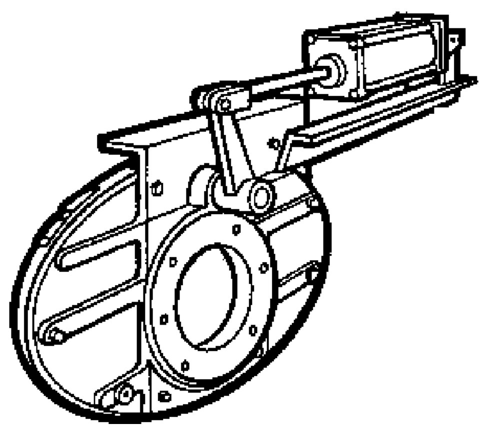


Figure 3-14
Rotary Slide Gate
Courtesy of United Conveyor Corp.

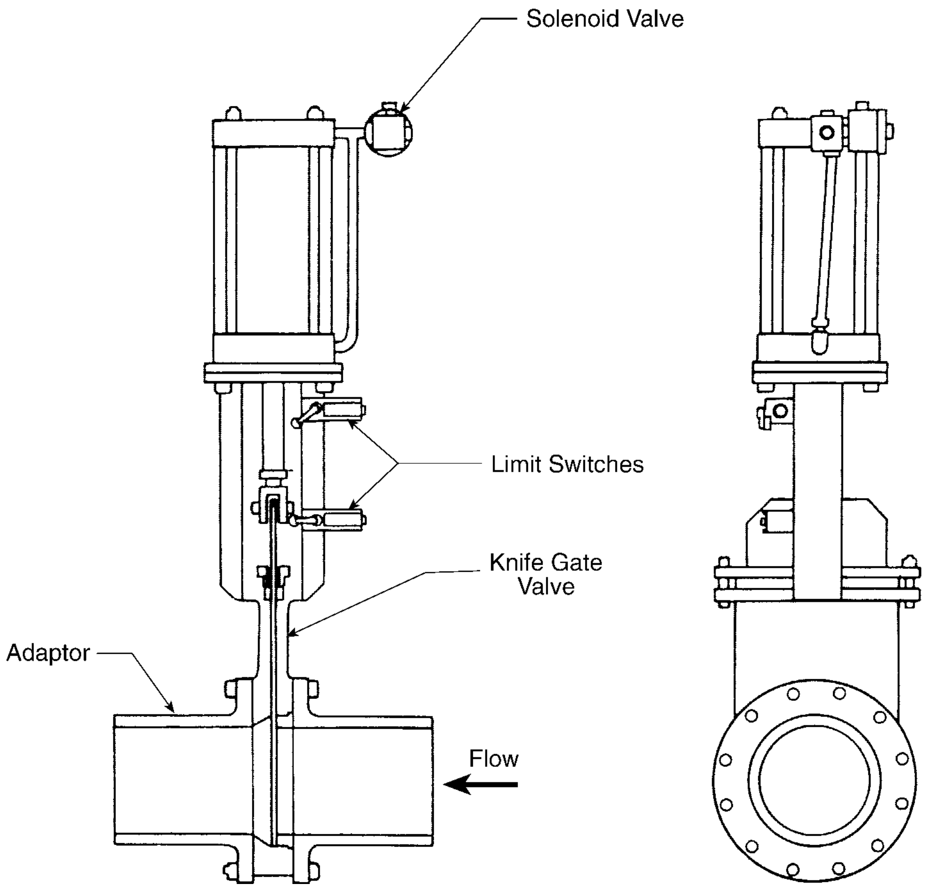


Figure 3-15
Straight-Line Slide Gate
Courtesy of Allen-Sherman-Hoff

3.1.7 Rotary Disc Sluice Valves

Rotary disc sluice valves, once used almost exclusively, have now been largely superceded by slide gates. A rotary disc gate, however, may still be considered whenever cost is a high priority.

Key O&M Cost Point

Rotary disc sluice valves, once used almost exclusively, have now been largely superceded by slide gates. A rotary disc gate, however, may still be considered whenever cost is a high priority.

A rotary disc sluice valve (sometimes called a *balanced valve*) is made by sandwiching a rotary disc wafer of approximately twice the nominal pipe diameter between eccentric cast alloy inlet and outlet sections (see Figure 3-16). This configuration results in a nearly straight-through flow path when the rotary disc is opened, minimizing turbulence and pressure drop. Ash lines with rotary disc valves must be flushed and purged after each use to prevent pluggage.

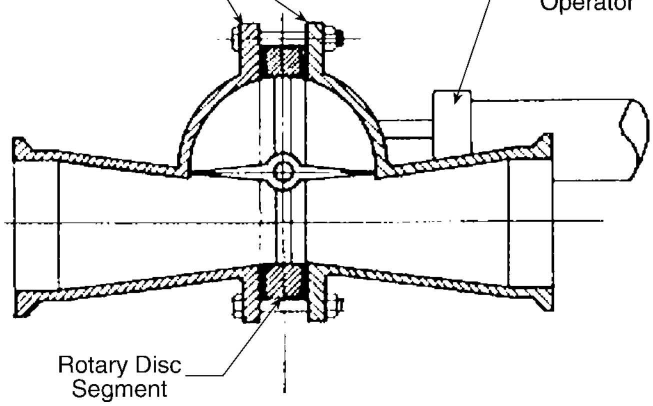


Figure 3-16
Rotary Disc Sluice Valve
Courtesy of United Conveyor Corp.

Key Technical Point

Ash lines with rotary disc valves must be flushed and purged after each use to prevent pluggage.

Because the disc leaks, it decants the water and leaves ash standing in the isolated line. Therefore, the next time the line is used, the standing ash can be pushed into a "plug" that blocks the line. This flaw, along with their inherently lower resistance to abrasive wear, has caused balanced valves to be largely phased out in favor of slide gates.

All of the valves and gates discussed can be fitted with a variety of accessories and operators ranging from manual handwheels to air or hydraulic cylinders. The valves can also be fitted with position-indicating limit switches (which are either recommended or required permissives on automatic systems) and input devices for graphic or mimic control panels.

3.1.8 Pyrites Hoppers for Pulverizers

Some pulverizers have built-in storage for rejects (commonly referred to as *pyrites*). Others require an external hopper that is usually part of the ash handling equipment and typically furnished by the ash system vendor. Figure 3-17 shows a typical hopper. The function of mill hoppers is twofold: to receive and store mill rejects (pyrites) and to do this in a way that prevents coal-laden air from escaping from the pulverizer.

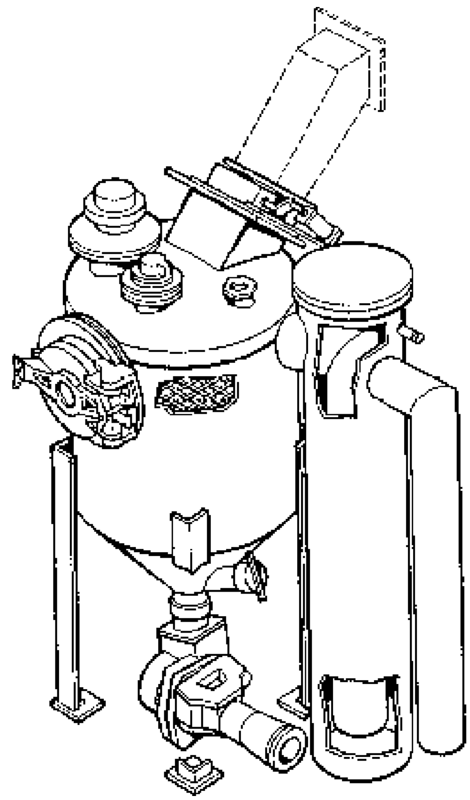


Figure 3-17
Pyrites Hopper
Courtesy of United Conveyor Corp.

Key Technical Point

The function of mill hoppers is twofold: to receive and store mill rejects (pyrites) and to do this in a way that prevents coal-laden air from escaping from the pulverizer.

This seal connection must be accomplished in a way that does not allow water to enter the mill in the event that the hydraulic conveyor line becomes plugged.

Hoppers should be fabricated of 1/4-inch (6.4-mm) carbon steel plate for normal service. Because mill rejects have a high sulfur content, there is a strong possibility that the hopper will be exposed to acidic water (low pH). If this is expected, a heavier mild steel or type 316 stainless steel should be used.

The usual method of attaining the seal against mill pressure is with a standing leg of water in a U-tube attached to the hopper. This water leg is calculated to have a pressure in excess of the maximum mill pressure expected.

A steady flow of approximately 5 gpm (315 ml/s) should be maintained in a seal leg to avoid loss or evaporation of the water. The bottom of a seal tube should be fitted with a manual drain for periodic removal of accumulated sludge.

Pyrites mill hoppers should also be fitted with the following:

- High material level detector
- Observation window
- Access door
- Grid to prevent oversized material from entering the pipeline
- Vacuum-relief valve
- Hopper isolating gate (which is closed during conveying or whenever the access door is open)
- A flushing nozzle directed toward the inlet of the jet pup
- A jet pump, usually 4 inches (100 mm) in size

3.1.9 Dewatering Bins and Accessories

For installations that handle bottom ash hydraulically and remove it from the site for final disposal, dewatering bins separate the ash and conveying water and store the ash until it is removed (usually by truck and occasionally by rail car) (see Figure 3-18).

Dewatering bins are almost always cylindrical, with a conical bottom and a discharge gate at the bottom of the cone. To discharge the dewatered ash into the removal vehicles, bins must have sufficient elevation; also, there must be both horizontal and vertical clearance underneath them. These requirements can result in having the center of mass of many tons of ash cantilevered at elevations of 75 feet (22.8 m) or more above grade. The power plant engineer should carefully check the proposed structure, especially wherever there is a recognized seismic risk.

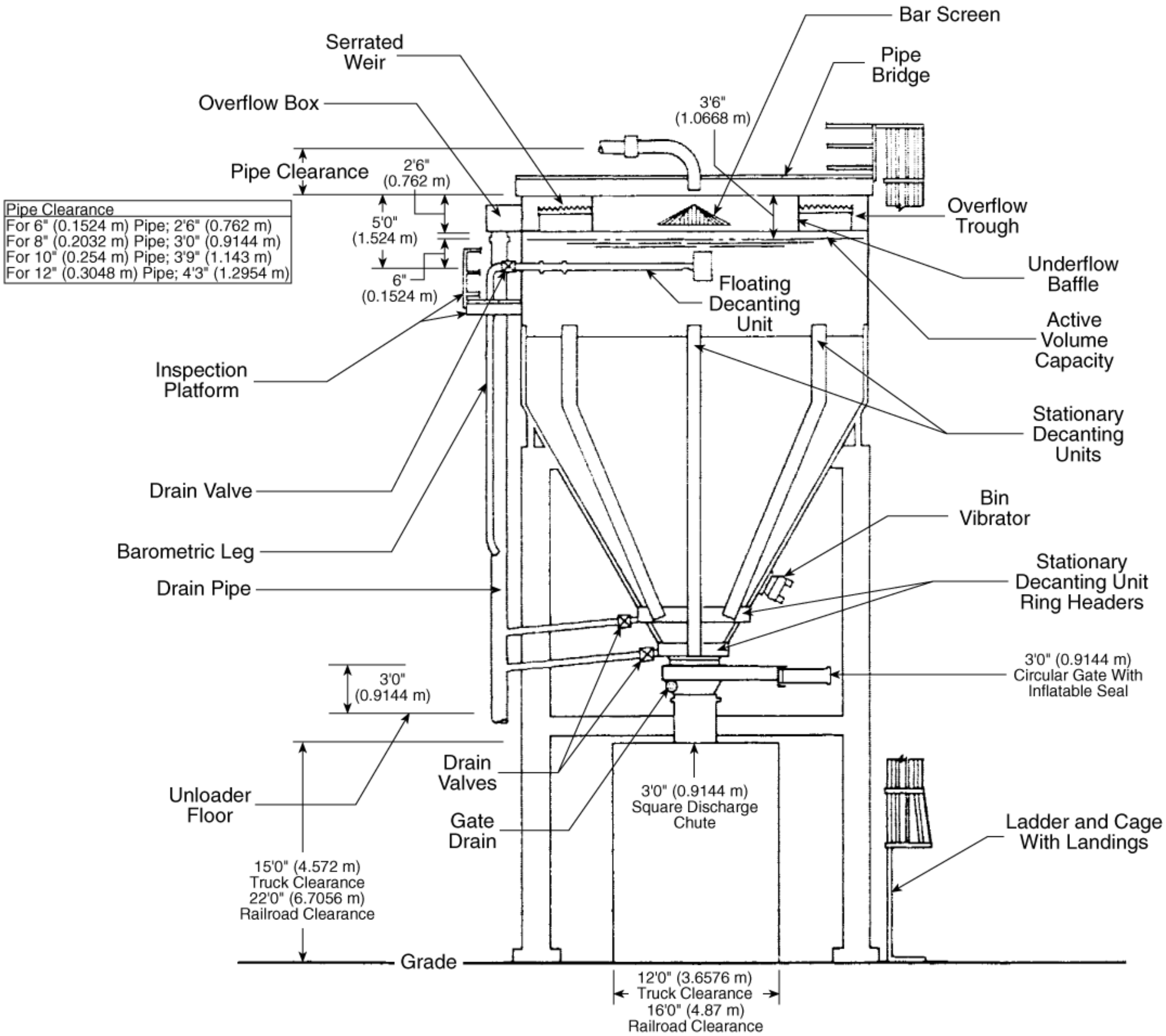


Figure 3-18
Dewatering Bin
Courtesy of Allen-Sherman-Hoff

As in the case of bottom ash hoppers, dewatering bin selection depends primarily on deciding the required storage volume. Since adequate decanting and dewatering of stored ash can usually be accomplished within 8 hours (28.8 Ksec), it is theoretically possible to operate with a single dewatering bin if a plant has more than 8 hours (28.8 Ksec) storage capacity in the water-impounded bottom ash hopper under the boiler.

This, however, implies a very rigid and unrealistic ash-unloading schedule. A system using only a single dewatering bin provides no redundancy for planned or corrective maintenance on the bin. Therefore, at all but the smallest plants, at least a pair of dewatering bins is used. After one bin is filled to capacity with ash and the dewatering cycle begins, ash is conveyed to the second bin. Dewatering bins should be sized for a combined net storage capacity representing 72 hours (260 Ksec) production of bottom ash at MCR.

Key Technical Point

Dewatering bins should be sized for a combined net storage capacity representing 72 hours (260 Ksec) production of bottom ash at MCR.

This allows for storage without removal over the weekend. Since dewatering bins are sized at MCR and boilers are not always operated at full load (especially on weekends), this volume is usually sufficient for storage actually required over long holiday weekends. The volume, however, should be considered on a case-by-case basis. The volume required is calculated on the basis of an assumed amount of bottom ash, a conservative but realistic density of ash, and the required period of storage.

The diameter of a dewatering bin is large compared to the inside width of a bottom ash hopper, and ash is discharged from a single central opening in the dewatering bin. To ensure that dewatered ash discharges from the outlet, a fairly steep lower cone angle is required. The quasi-standard in the industry of 55 to 60 degrees (0.96 to 01.1 radians) from the horizontal is recommended.

Discharge Skirt

To minimize short-circuiting by incoming mixtures of water and fine ash particles directly to the overflow weir, a circular skirt is usually provided around the discharge point and should extend 2–3 feet (60–90 cm) below the normal water level. This prevents the initial downward velocity of the water and ash from being dissipated too rapidly and retains sufficient differences between the downward velocity of ash particles and the rise rate of the water being displaced.

Underflow Baffle

As bottom ash is formed in the furnace, some clinkers are developed that are either porous or contain sufficient gas pockets to cause the clinkers to float. In the dewatering bin, these “floaters” can eventually reach and then travel over the overflow weirs into the drain, eventually plugging the drain piping system. To prevent this, an overflow baffle is used. This is a circumferential skirt that extends from approximately 1 foot (30 cm) below the water line to slightly above the water line. Floaters collect against this baffle until the bin is full and are discharged with the ash whenever the bin is emptied.

Bar Screen

Most commercial standard designs for dewatering bins discharge the ash/water slurry against a target plate or bar screen. Both have the same intent: to “throw” ash particles outward to the sides of the dewatering bins, thus causing more complete filling. The bar screen also allows fine particles to go straight through and throws coarse particles to the sides, where they act as a filter—preventing the fine particles from clogging the screens of the dewatering element.

Dewatering Elements

All major vendors offer dewatering elements with similar primary components, such as stainless steel screens, placed over steel pipe with windows cut out or over steel channels. The number of main dewatering elements is, or should be, a function of the bin diameter. The following is recommended:

- Diameters to 16 feet (4.8 m): 4 elements at 90 degrees (1.6 radians)
- Diameters 16–25 feet (4.8–7.6 m): 6 elements at 60 degrees (1.1 radians)
- Diameters 26–35 feet (7.7–12 m): 8 elements at 45 degrees (0.78 radians)
- Diameters 36–45 feet (12.1–14 m): 10 elements
- Diameters 46–55 feet (14–17 m): 12 elements

Key Technical Point

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- **Diameters 36–45 feet (12.1–14 m): 10 elements**
- **Diameters 46–55 feet (14–17 m): 12 elements**

A judgment can be made if the size selected for the dewatering bin is approximately at one of the size breaks. The main dewatering elements should have screens with diameter or slotted holes from 1/16 to 1/8 inch (1.6 to 3.2 mm) punched on staggered centers 1-1/2 times the diameter (that is, 3/32-inch [2.38 mm] centers for 1/16-inch [1.6 mm] holes and 3/16-inch [4.7 mm] centers for 1/8-inch [3.2 mm] holes) to allow proper dewatering.

Key Technical Point

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Screens with the minimum recommended size openings minimize the amount of fine particle carry-over (also called *fines*) during dewatering. Conversely, the larger size 1/8-inch (3.2 mm) opening allows some additional carry-over but dewaters more quickly. The size ranges recommended above provide for acceptable performance in either regard.

Discharge Doors

Some vendors furnish a vertical-lifting discharge door and enclosure similar to that described previously for the bottom ash hopper. Several others furnish a horizontal discharge gate with an inflatable seal for positive shutoff to prevent leakage through the gate. While rubber-sealed horizontal gates require more maintenance, they are less likely to leak and are recommended where a gate leakage of 3 to 10 gpm (190 to 630 ml/s) cannot be conveniently accepted.

This degree of watertightness is retained only when both the gate and seal are kept in good adjustment and repair. To cope with leakage through the gate, most manufacturers provide a drip trough or pan that directs the flow to a drain. Even if the gate is expected to be watertight, such a drain must be provided. Additionally, the drain should be piped to a telltale so that the need for gate adjustment/maintenance is known as it arises.

Dewatering bin discharge doors are usually hydraulically operated through a four-way valve by compressed air that pressurizes a fluid reservoir. Wherever the dewatering bin complex is too far from the plant for a supply of its compressed air, the discharge door is operated hydraulically by a motor-driven hydraulic pump package.

Freeze Protection

Dewatering bin freeze protection is required on the drain lines and valves as well as on the lowest portion of the bin cone. If the contents of the bin cone just above the discharge door are kept fluid and can discharge, the material above this can also be made to slough off and discharge, especially when aided by vibrators. Thermostatically controlled heat applied to the bottom of the cone—with approximately the lowest 8 feet (2.4 m) insulated by 2 inches (50 mm) of dense fiberglass or its equivalent—is sufficient to prevent freezing. The heaters' control thermostats should be used in combination with ambient air thermostats to call for heat only in subfreezing conditions.

The drain lines and drain valves should be heat traced and insulated. The heat tracing should also be controlled by ambient air thermostats, so that heat is called for only in subfreezing weather.

Vibrators

Vibrators are furnished by most vendors as a standard part of the dewatering bin package and should be specified to be furnished. Vibrators are effective in several situations, including:

- Removing deposits of ash that remain in a nearly empty bin
- Smoothing out erratic discharge
- Reestablishing discharge if it is interrupted by arching or rat holing

Brackets should be supplied for mounting four vibrators at 90-degree (1.6-radian) intervals as part of the dewatering bin structure. Original equipment should include one vibrator on any bin up to 16 feet (5 m) in diameter and two vibrators 180 degrees (3.1 radians) apart on any bin larger than 16 feet (5 m) in diameter. Additional vibrators can be added as dictated by field conditions after plant startup. The design of the dewatering bin vibrator control shall be manual with momentary contact. Never energize the vibrators with the discharge door closed or the ash will "pack," resulting in plugging of the discharge.

> **Key Technical Point**
>
> **The design of the dewatering bin vibrator control shall be manual with momentary contact. Never energize the vibrators with the discharge door closed or the ash will "pack," resulting in plugging of the discharge.**

Settling Tank

Water that overflows or is decanted from the dewatering bins is drained (almost always by gravity) into the settling tank. There, further settling of particulates removes most of the fines that are carried over.

The settling tank should be sized so that the rise rate of the water due to displacement by the total of all possible simultaneous inputs is less than the settling velocity of any specified size (weight) particle. A sizing standard that theoretically results in settling out particles greater than 100 microns (100 micrometers) with a specific gravity of 2.0 or higher is used in designing a settling tank.

> **Key Technical Point**
>
> **A sizing standard that theoretically results in settling out particles greater than 100 microns (100 micrometers) with a specific gravity of 2.0 or higher is used in designing a settling tank.**

To aid the removal of settled-out sludge, the recommended slope for the cone of the settling tank is 45 degrees (0.783 radians). The bottom of the tank should be fitted with a sludge removal system consisting of a slurry pump that takes suction from the bottom of the settling tank and a series of agitating nozzles placed to enhance the flow of sludge into the pump inlet piping. It has been found that continuous or near continuous sludge removal is best. If intermittent removal is attempted, it is usually impossible to remove the accumulated sludge without using large quantities of agitating water for extended periods of time. This causes increased particulate carry-over from the tank and should be avoided.

For reasons noted above, the settling tank is sized to provide a certain cross-sectional area rather than a specified volume. The cylindrical height of the settling tank, therefore, is minimal—usually only enough to provide the necessary stiffening and support of the conical bottom. Typically, this is approximately 4 feet (1.2 m) high.

Settling tank performance is affected significantly by the following characteristics: specific gravity of the ash particles, the temperature of the water being clarified (viscosity), ash shape, concentration and turbulence, and the nominal size of particles that settle out.

Surge Tank

In contrast to the settling tank just described, the surge tank in a closed, recirculated water system is a volumetrically sized storage vessel. A conservatively sized surge tank can store all of the water used in the recirculating system and release it to the system as required. This storage requirement is important during plant shutdowns or at any other time that all vessels must be emptied of water (for example, during inspection and repair).

The construction of the surge tank is similar to that of the settling tank: it usually has a conical bottom and a sludge-removal system. As with a settling tank, sludge suction piping and agitating nozzles are provided at the bottom of the surge tank. A cone angle of 45 degrees (0.783 radians) is recommended for surge tanks; 35 degrees (0.61 radians) from the horizontal is considered the minimum.

Key Technical Point

A cone angle of 45 degrees (0.783 radians) is recommended for surge tanks; 35 degrees (0.61 radians) from the horizontal is considered the minimum.

The total height of the surge tank is determined by several requirements in addition to the storage volume. The pump suction piping system for the system water supply is set about 10 feet (3 m) above the bottom of the tank to avoid taking in settled sludge. An additional depth of water—approximately 4 feet (1.2 m)—is needed to provide a positive head above the pump inlets. An additional “dead band” of water, approximately 2 feet (0.6 m) deep, is allowed for reaction by level control instrumentation.

The sum of these allowances places the minimum usable water level approximately 16 feet (5 m) above the bottom of the tank. The required volume of water is then provided above that level; the top of the tank is placed 1 foot (1/3 m) above this water surface (and 6 inches [15 cm] above the emergency overflow).

The working volume of the surge tank is thus the total volume contained above the minimum level that is set as described. For a system with two dewatering bins, this should at least equal the gross volume of one dewatering bin plus the volume of all hoppers, tanks, and sumps that might be returned to the surge tank. For each additional dewatering bin in the system, the gross volume of the dewatering bin should be added to the required volume of the surge tank.

3.1.10 Mechanical Bottom Ash System

The mechanical bottom ash system (MBAS) is also known as *submerged chain conveyor* (SCC), *submerged scraper conveyor* (SSC), *submerged drag chain conveyor* (SDCC), *scraper bar*, *wet carrier*, or *drag bar conveyor*. Because of their many advantages including power, water, steel, installation, and space savings, MBASs are gaining popularity in the power industry. Most scraper bar conveyors are similar.

Figures 3-19 and 3-20 show the components of an MBAS. A rectangular water-filled tank is placed beneath the boiler. Seal plates attached to the boiler-tube headers extend downward into the water-filled tank. They provide a seal against changes in boiler pressure and a means to accommodate the downward expansion of the boiler outlet as the plant heats from shutdown to operating temperature. The discharge end of the tank (beyond the seal plates) rises at an incline of approximately 30 degrees (0.52 radians).

Another type of MBAS is a dry flight conveyor (DFC). It operates continuously and transports dry material at elevated temperatures through an enclosed conveyor trough. The DFC has become a viable option for all types of wet systems because it can transport bottom ash directly to a storage silo or intermediate point (that is, a transfer tank).

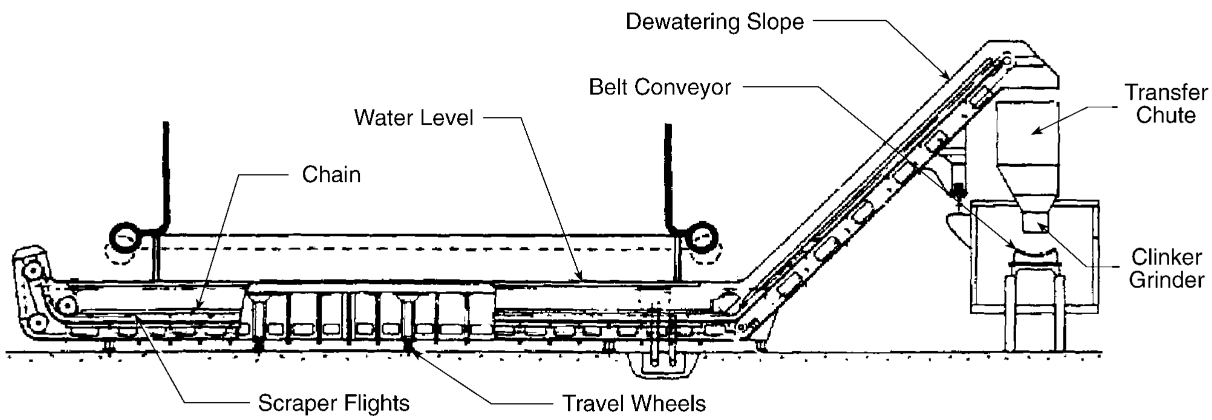

Figure 3-19
Submerged Chain Conveyor
Courtesy of Combustion Engineering Co.

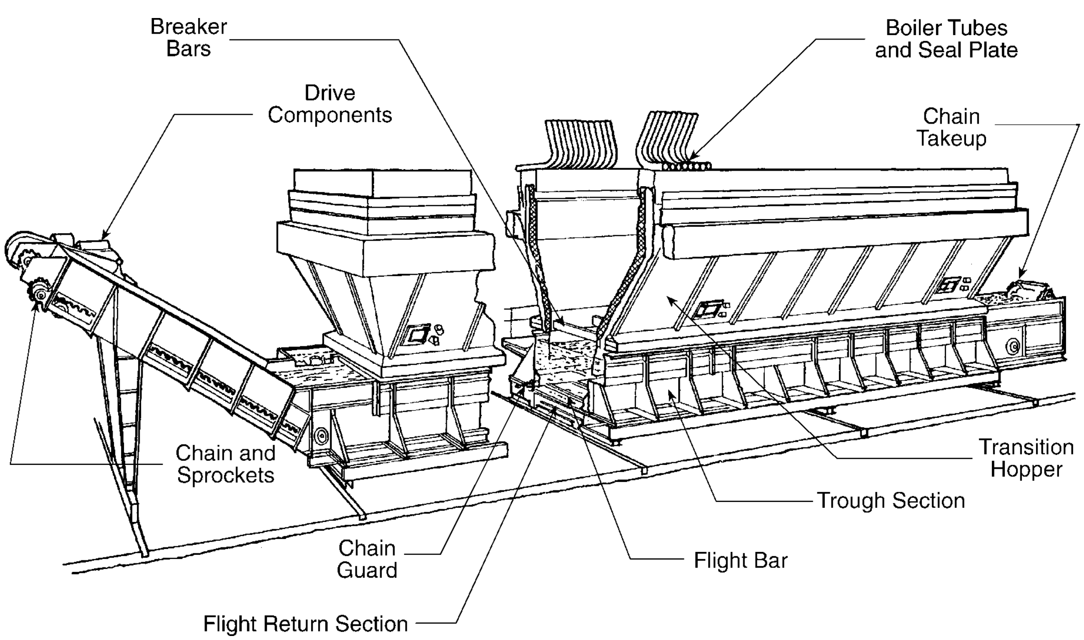

Figure 3-20
Submerged Chain Conveyor
Courtesy of Fuller Company

Through a series of sprockets and idlers on each side of the tank and incline, a pair of chains is driven continuously along the length of the tank. Flights, usually in the form of steel angles, are connected to the driven chains on each side. They sweep across the bottom of the tank, up the incline, and return through a "false bottom" on the tank. This false bottom is usually referred to as the *lower trough* while the water-impounded tank is called the *upper trough*.

The chain and flights (drag bars) are driven by a variable speed drive unit through the head sprockets at the top of this incline. Chain tension and adjustment are made by tail shaft takeup units at the back end of the tank.

Dewatering of the ash is accomplished by draining as it is pushed up the incline by the conveyor flights. The water runs through the interstitial spaces and back to the tank, so that ash contains approximately 15–25% moisture by weight when it is discharged at the end of the incline. This discharge can travel either through a grid, a vibrating grizzly, a crusher to size the larger chunks of ash, or directly to the removal equipment.

The removal equipment is usually a belt conveyor, although on small installations, it can be a dump truck parked under the discharge until it is filled. The belt conveyors discharge the collected ash through bucket elevators into silos, from which the ash is periodically removed for ultimate disposal.

To guard the chain and sprockets, protective structural steel is welded to the tank sides and extends over the chain to protect it from direct impact by ash and slag. At the top of the incline, water-jetting nozzles are oriented to wash the chain and remove any ash before it is engaged by the drive sprockets. A variable speed drive train with a turnover of approximately 6:1 is to be used in the MBAS to allow dewatering and volume control.

Key Technical Point

A variable speed drive train with a turnover of approximately 6:1 is to be used in the MBAS to allow dewatering and volume control.

In the middle of its speed range, it should be able to meet the design capacity for ash removal. The drive should be equipped with a torque-limiting device that protects the drive train while allowing catch-up operation with a filled trough.

Because the comparatively small surface area of the flight bars is in contact with the much larger area of the trough, wear on the flight bars could occur at a rate greater than that on the trough. To offset this, flight bars are usually fabricated from material of much higher hardness. The incline and portions of the upper trough are lined with abrasion-resistant plate at least 1/2 inch (12 mm) thick. The intent is to get approximately equal, calculable life from both types of components so that they can be replaced at the same outage interval. In the dry return trough, wear strips are usually used. Since the wear is localized, these wear strips should be harder and thicker. The ultimate success or failure of an MBAS depends largely on the life of the chain used. Replace the chains with a matched set on both sides of the ash tank.

Key O&M Cost Point

The ultimate success or failure of an MBAS depends largely on the life of the chain used. Replace the chains with a matched set on both sides of the ash tank.

The links (wearing surface) are annealed and case hardened to ~500–600 BHN (~6.5–6.9 Mohs). The failure mode of these chains seems to be a gradual lengthening caused by wear on the inside of the links, resulting in disengagement from the sprockets. The chain, if replaced, should be replaced as a matched set on both sides of the tank.

The sprocket bearings should have a lubrication system that allows greasing of all bearings from outside the tank. Some vendors require a water purge of submerged bearings. Since this requires a significant amount of filtered water, the prospective user is advised to check this requirement carefully.

3.2 Ash Handling Systems

Section 3.1 provides an overview of the equipment and components used for ash handling. The following describes how these devices can be combined into systems to fulfill the various requirements for ash handling.

The two principal types of systems are described here: the conventional bottom ash system (impounded water) and the MBAS. Dry (pneumatic) bottom ash systems are not common and are therefore not considered a "principal" type of system; however, a brief description is included in Section 3.2.3. Bottom ash control systems are discussed in Section 3.2.4.

Schematic diagrams of these major systems are presented to show system operation and to identify the required components. The latter information is especially important to project engineers and those who evaluate proposals. Ash system vendors do not furnish all components, and noncompliance with specifications (or requirements) is not always clearly stated in bids and proposals.

The choice of system type can be simple. Some sites preclude the use of ash holding ponds, and others restrict the use of water. Some system choices may not provide the required capacity. Further, the economies of each choice are site-specific. When all such considerations are taken into account, the choices are narrowed and perhaps limited to a single possibility.

3.2.1 Impounded Water Bottom Ash System

The established standard for most U.S. utility power plants is the impounded water bottom ash system. This system operates with either a maintained (full) or nonmaintained water level.

Figure 3-21 shows the piping for a bottom ash hopper. With maintained water level, a level controller (usually an air-bubbler type) attempts to maintain the hopper full of water. When ash is conveyed and large amounts of water are withdrawn, the controls open the water supply valve to compensate for the loss and maintain the water level. The full level of water provides maximum protection to the refractory and hopper. It also imparts buoyancy to the impounded ash, which makes it easier to sluice to the hopper outlet. The maintained level operation is the recommended mode, especially for large hoppers.

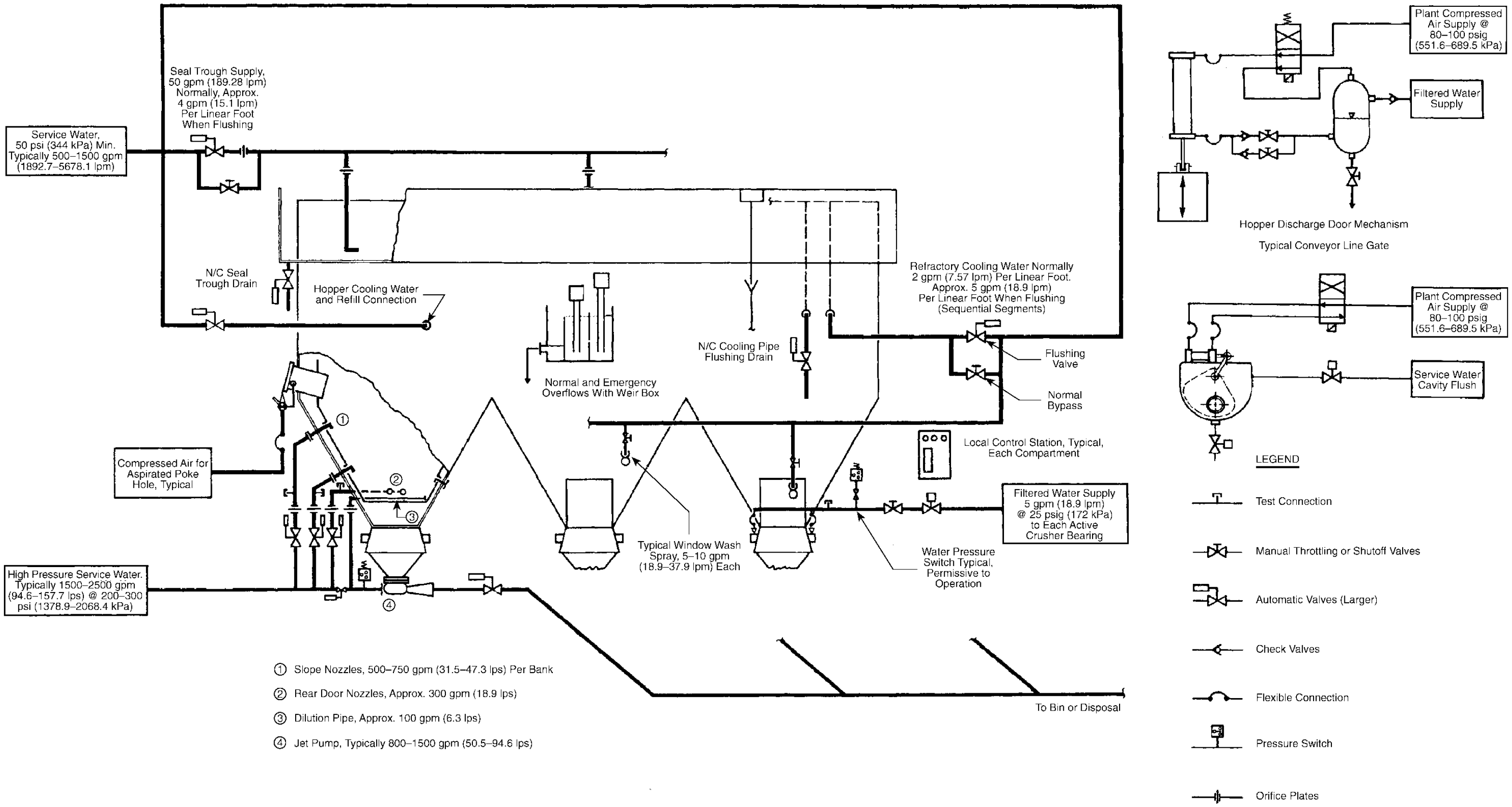

Figure 3-21
Bottom Ash Hopper Piping Diagram
Courtesy of United Conveyor Corp.

The nonmaintained mode, however, is specified by most power plant owners because operators prefer to allow the water level in the hopper to fall to the point that poke hole(s) can be opened to observe at least daily the inside of the hopper. This visual inspection ensures that clinkers and stalagmite are not forming unobserved within the hopper. However, when the level of water is drawn down, it leaves decanted ash in the hopper. This ash is more difficult to transport to the outlet than ash that settles. The slope jetting nozzles—provided to move ash—frequently tunnel through the impounded ash without moving it.

It is recommended that the maintained level design be specified and used. When the hopper interior is inspected, the water makeup valve can be disabled and the water drawn down for this purpose. Most sluice bottom ash systems are designed to handle 100 tons (91,000 kg) per hour.

Key Technical Point

Most sluice bottom ash systems are designed to handle 100 tons (91,000 kg) per hour.

This "standard" capacity allows vendors to use predeveloped engineering parameters. It also allows the bottom ash produced in an 8-hour (28.8 Ksec) shift to be conveyed in approximately 1-1/2 to 2 hours (5.4 to 7.2 Ksec). For even the largest boilers or those firing coal with the highest ash content, the time to convey is not appreciably increased because most of the elapsed time is spent on nonconveying activities such as startup, sequencing, and shutdown.

Figure 3-22 illustrates hopper construction and its auxiliary equipment. The following is a brief description of bottom ash system control operation:

1. Gate and valve positions and water supply pressures are verified with interlocks.
2. Water is turned on to the dilution pump, jet pump, and crusher seals.
3. Nozzles opposite the closed door are turned on to agitate and fluidize the packed ash.
4. The discharge door is opened, allowing water and ash to be transported.
5. The uppermost bank of slope nozzles on one side of the compartment is activated for approximately 5 minutes (300 s), followed by each bank in turn.
6. Either on a timed cycle or as determined by the operator (the sound of water alone being removed from an empty hopper is different from the sound of an ash-water mixture leaving), the vertical lifting door is closed.
7. The crusher seal-water and crusher are turned off.
8. Steps 1 through 7 are repeated for each of the other hopper compartment(s).
9. The jet pump water supply is turned off after a purge period.
10. The seal trough and cooling water pipes are flushed.
11. The system shuts down.

In this manner, the bottom ash is transported to the dewatering bins or to an ash pond.

The operation is similar in a system that uses a mechanical pump instead of a jet pump, but additional instrumentation is required to maintain positive head and flow to the mechanical pump (for example, whenever the vertical lifting doors are closed).

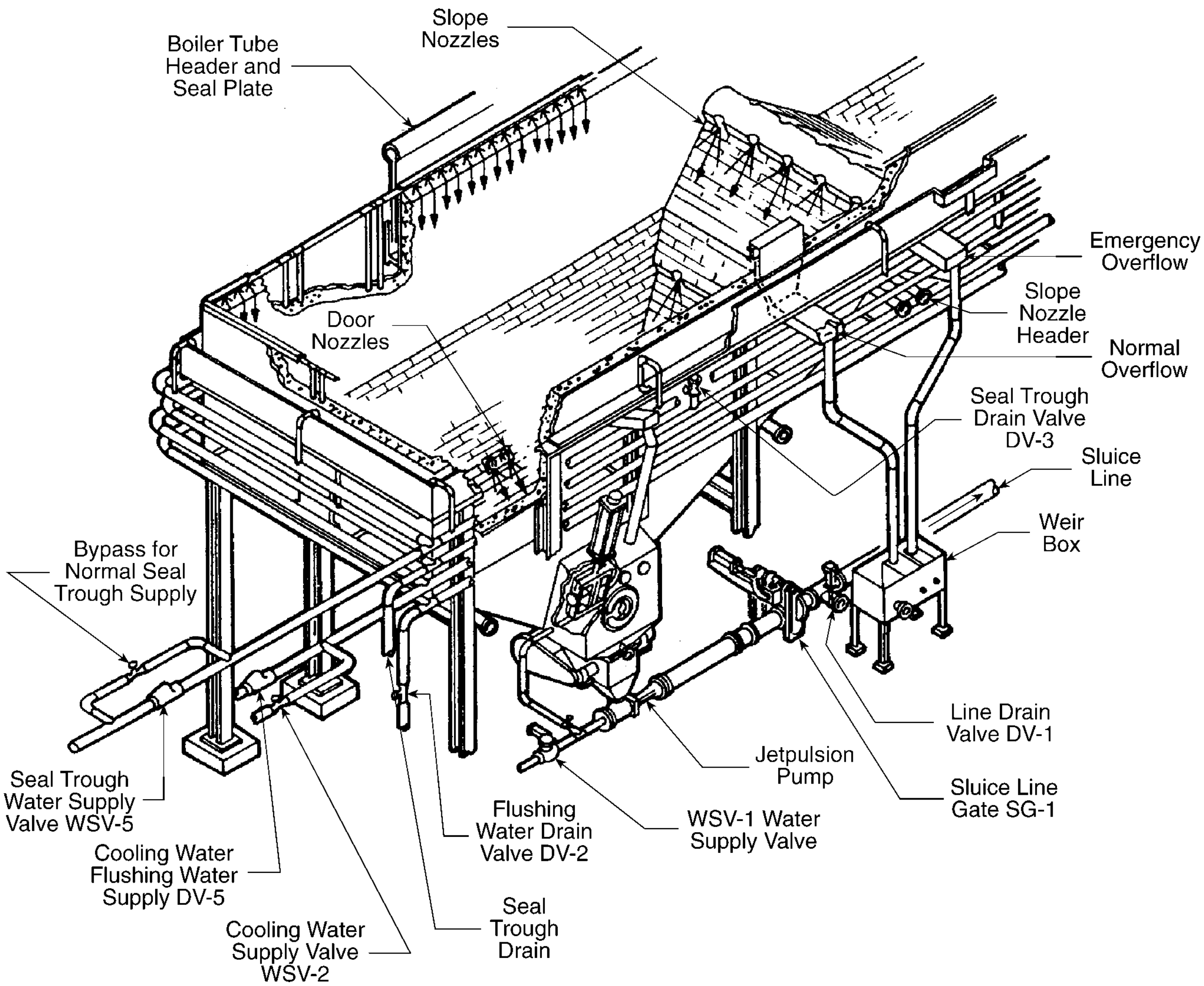

Figure 3-22
Automated Impounded Water Bottom Ash System
Courtesy of United Conveyor Corp.

Recirculating Water Systems

Most plants being built today are required to meet “zero discharge” criteria, which prevent contaminated water from being discharged.

Key O&M Cost Point

Most plants being built today are required to meet “zero discharge” criteria, which prevent contaminated water from being discharged.

The main components of the recirculating water (storage) systems are rather passive in operation. They serve largely to decant, clarify, and store the water that is used in the ash handling system. Information presented earlier in this section provides insight into the way these components function and is not repeated here. This description concentrates on system operation. Figure 3-23 schematically illustrates a typical recirculating water system.

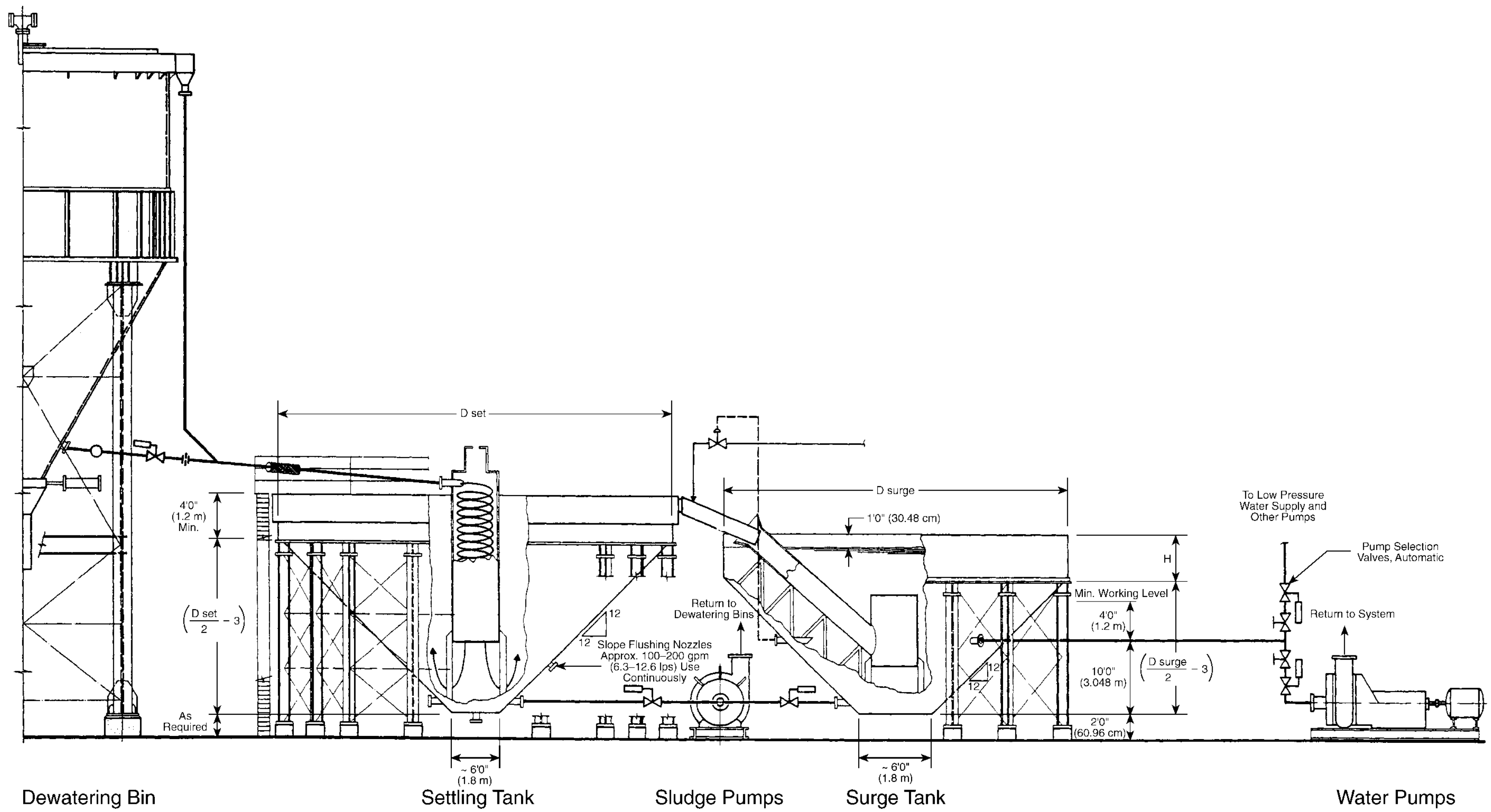

Figure 3-23
Recirculating Water System
Courtesy of United Conveyor Corp.

Commonly used recirculating water systems include dewatering bins that discharge water to a settling tank. This tank in turn discharges to a surge tank, from which system water is pumped. Entrained solids settle out in the settling tank to form sludge on the bottom and must be pumped out of the tank. Additional settling occurs in the surge tank.

The surge tank handles surge volume, for example, the water that is drained while decanting a dewatering bin. In addition, makeup water is added to the surge tank to compensate for water removed with dewatered ash (a certain amount is required to ensure that dewatered ash will flow) as well as water lost by evaporation and other system losses. Makeup water is commonly controlled by a pneumatic proportional control that consists of a transmitter, controller, manual/automatic station, and control valve. Accuracy is not critical if an adequate level is maintained to meet system requirements.

The surge tank should be equipped with level switches to alarm high- and low-level conditions, and on low-low level to shut down the pumps that draw water from the tank.

The settling and surge tanks must be equipped with means of removing the sludge that settles out in each of them. Sludge removal can be intermittent or continuous. Continuous systems remove dense sludge through a number of nozzles in the bottom of the tank. Intermittent removal is usually accomplished by pumping from a few large nozzles while the sludge on the bottom of the tank is slurried by agitating nozzles. Intermittent removal arrangements also require automatic back-flushing of the sludge suction lines prior to pumping to clear sediment that could plug the suction lines of the sludge pumps.

Recirculating water pumps generally handle slightly dirty water, while sludge pumps handle sludge or very dirty water. Both types of pumps typically require clean (filtered) seal water, usually at a pressure slightly higher than the discharge pressure of the recirculation pumps. Seal water must be supplied to a pump whenever it can be flooded through the suction or discharge. Suction and discharge valves should be interlocked so that they do not open unless water is being supplied to the seals. Pressure or flow switches may be used to prove the supply of seal water. These pumps should also be equipped with suction pressure switches and not be allowed to start unless suction and discharge gates are verified to be open and the pumps supplied with adequate seal water pressure.

At some plants (particularly the ones burning western coal), the recirculated water can become alkaline, creating calcium buildup problems in the water supply and sluice piping. Where this problem exists, it may be necessary to inject acid into the recirculation system water. This allows the water to hold a much higher concentration of minerals in suspension and, when performed in conjunction with blowdown, the scaling problem should be resolved.

3.2.2 Mechanical Bottom Ash System

Advantages of the MBAS include the following: low power requirements, no *conveying* water usage, smaller space requirements, lower headroom requirements (steel savings), elimination of the need for dewatering bins (although these may be replaced by storage silos), and lower capital cost.

Key O&M Cost Point

Advantages of the MBAS include the following: low power requirements, no *conveying* water usage, smaller space requirements, lower headroom requirements (steel savings), elimination of the need for dewatering bins (although these may be replaced by storage silos), and lower capital cost.

Design and operational challenges that must be overcome for successful application include slag falls, limited storage capacity within the MBAS, and the need to cool the comparatively small amount of water used by the system. MBAS layout is shown in Figure 3-24.

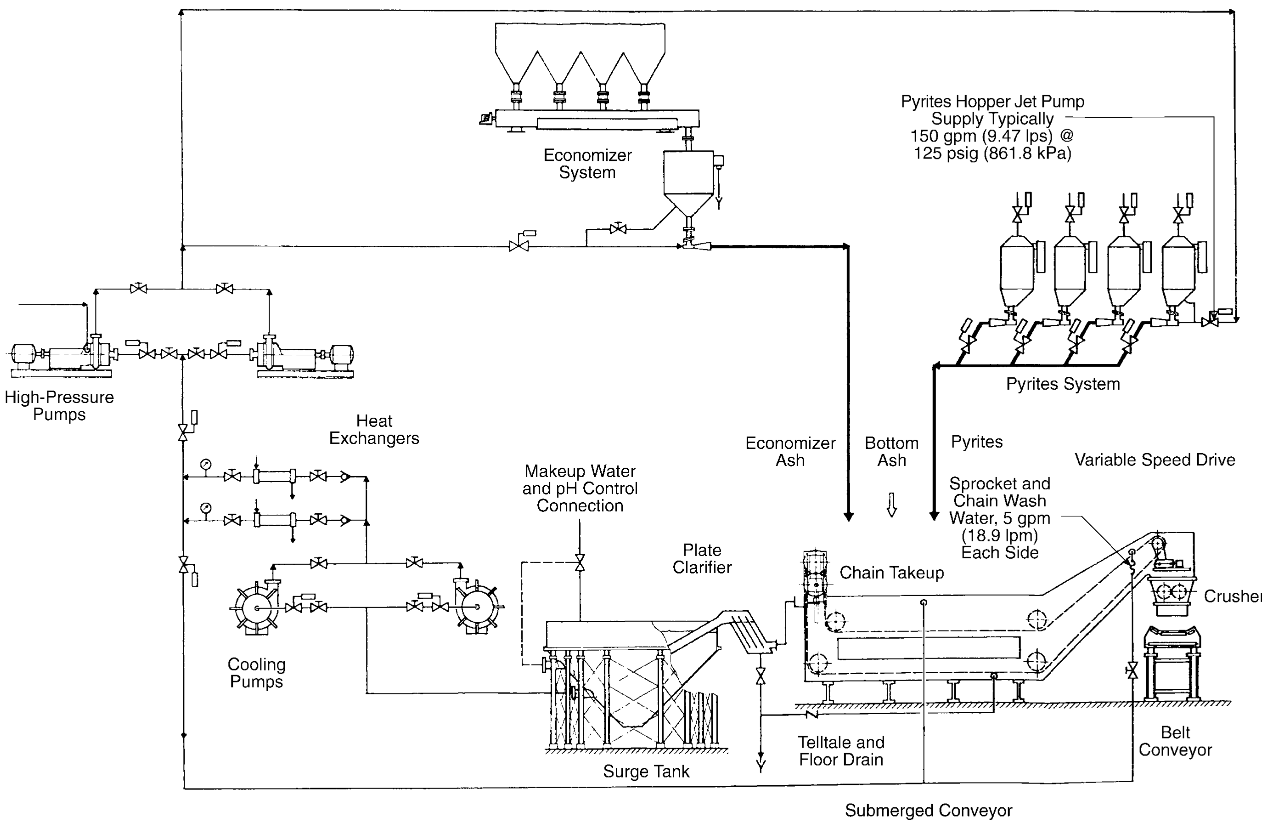

Figure 3-24
Mechanical Bottom Ash System Layout
Courtesy of United Conveyor Corp.

The primary part of the MBAS is a rectangular water impound tank placed beneath the boiler with an incline of approximately 30 degrees (0.51 radians) at one end. The drag conveyor within the tank carries ash up the incline slowly enough that most interstitial water drains from the ash and runs down the incline into the tank. The dewatered ash is dumped at the top of the incline.

The recommended variable speed drive allows the chain (and hence ash removal) speed to be varied for optimum dewatering with minimum wear. It also provides for increased speed to catch up following an upset.

Conveyor tank overflow is piped to a surge tank or, in some cases, through a parallel plate-clarifier and then to a surge tank. The surge tank should be able to hold at least the water volume of the conveyor tank; ideally, it should hold the total water in the system. At this tank, makeup water is added to the system as required, and pH is controlled.

For installations where the overflow cannot drain into the surge tank, a below grade sump can be used. In such cases, pump selection and maintenance become more complicated and costly. Sumps should be avoided (if possible) because draining by gravity will always be more reliable and inexpensive—if there is adequate elevation difference between vessels. Because a mechanical conveyor has a smaller amount of water than a conventional impounded water hopper, the hot ash heats the water and significantly increases the temperature.

Key Technical Point

Because a mechanical conveyor has a smaller amount of water than a conventional impounded water hopper, the hot ash heats the water and significantly increases the temperature.

Therefore, some type of ash cooling is required. This can be accomplished in an ash pond or a cooling tower. Because the MBAS is intended to be independent of or to eliminate ash ponds or cooling towers, heat exchangers are usually used for cooling. However, because the overflow water contains a significant amount of ash, any heat exchanger used is subject to fouling. For this reason, two full-capacity units (the recommended configuration) are usually installed. This allows one unit to be off-line for cleaning while the other carries the full load.

Unless a sump pit with sump pumps is used, cooling water pumps must be provided. These take suction from the surge tank and pump the water through the heat exchangers and the rest of the system. Again, two full-capacity pumps (one standby) are recommended. Because of the particulate carry-over in this water, slurry pumps or Ni-Hard fitted pumps should be used instead of ordinary water pumps.

These pumps are adequate for circulating water back to the conveyor tank. However, if pyrites removal, air-heater ash, or economizer ash is also part of the system, a booster pump must be provided. There should be two full-capacity units (one for standby). Water diverted for such additional uses should be returned to the conveyor as quickly as possible because it is part of the total needed to maintain the temperature at the design point.

3.2.3 Dry (Pneumatic) Bottom Ash Systems

Although dry (pneumatic) bottom ash systems are not as common as systems that use water-filled hoppers or troughs, a brief technical description of such systems is provided in this section.

The principal complication associated with dry collection and transport of bottom ash is the need to sufficiently reduce the ash temperature without the quenching effect of a water-filled hopper or trough at the bottom of the boiler. Adequate cooling of the ash allows the ash transport system to be constructed of standard, cost-effective materials. This cooling can usually be accomplished using a suitably sized storage hopper at the bottom of the boiler, which allows sufficient dwell time for the hot ash to cool by radiation and conduction. Alternatively, more active (and expensive) approaches, such as water-cooled screw conveyors, can be used.

Conceptually, all pneumatic system design types convey bulk material through a pipeline using compressed or evacuated gas as the conveying medium. Air is the most commonly used gas but may not be selected for use with reactive materials. The conveying medium may be liberally mixed with the bulk material, allowing the individual particles to travel in an airborne condition along the pipeline, or the bulk material may be completely solid without any fluidization or mixing with the gas. Between these extreme conveying regimes, a wide range of intermediate regimes is possible, depending on the transfer or injection system design objectives. The pneumatic conveying system designer should select an appropriate regime to economically target the objectives of the system requirements while considering any restraints that may be imposed by the characteristics of the bulk material.

If allowed to convey at high velocities, abrasive materials (such as bottom ash) will quickly erode the piping system. The system's energy consumption also increases as higher conveying velocities are used. Nonfluidizing dense-phase systems convey at a lower velocity than other types of pneumatic systems and may, therefore, consume less energy and require less maintenance. Figure 3-25 shows a simplified schematic of a dense-phase pneumatic bottom ash conveying system.

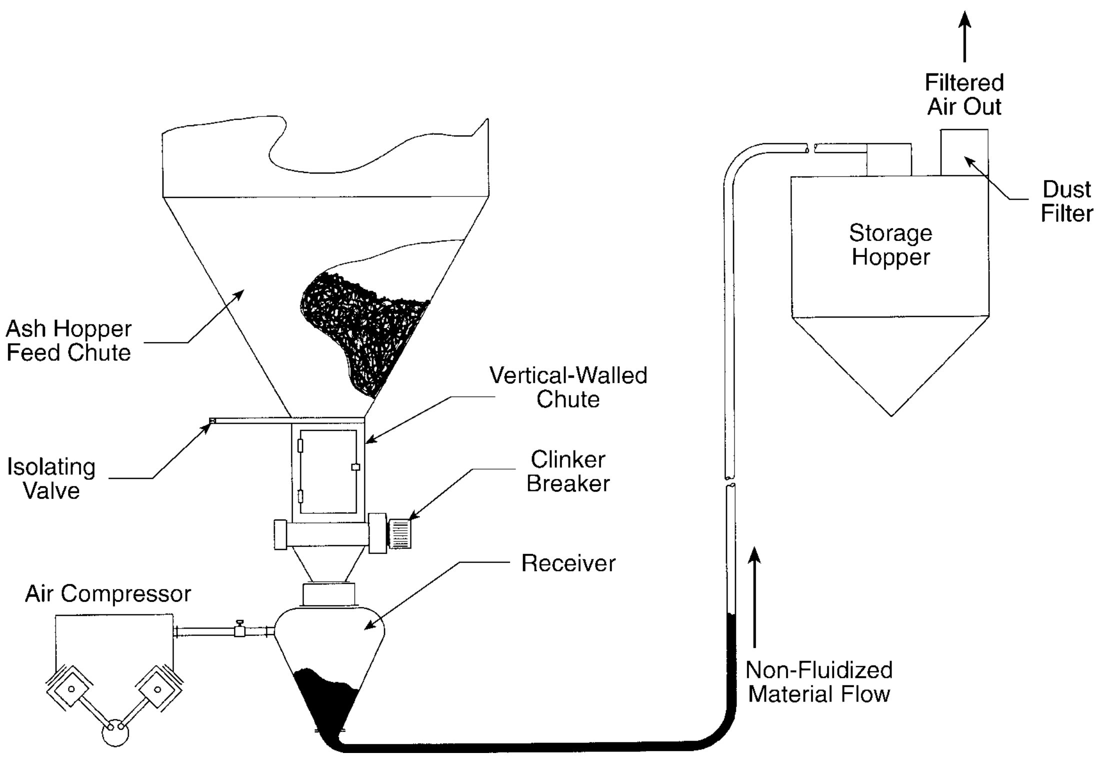

Figure 3-25
Dense-Phase Pneumatic Bottom Ash System
Courtesy of United Conveyor Corp.

3.2.4 Ash Handling System Controls

Ash handling system controls are the human interface to the system and have a number of points that must be monitored during operation. Ash handling systems are hydraulic, pneumatic, and mechanical processes where most variables cannot be observed without instrumentation and generally have several components that require operation and monitoring. In addition, these systems are necessarily distributed throughout the boiler and ash disposal areas. The following discussion concerns general control practices as they are applied to ash handling systems and defines some types of control systems. Monitoring the ash handling system and its components for safe and correct operation is of primary importance. Safe operation protects the personnel, the plant, and the ash handling equipment itself.

Key Human Performance Point

Monitoring the ash handling system and its components for safe and correct operation is of primary importance. Safe operation protects the personnel, the plant, and the ash handling equipment itself.

Monitoring includes instrumentation to monitor operating temperatures and pressures, motor currents, and other operating variables. Correct operation of a system allows it to function as it was designed. There are safe situations in which the system may not be working correctly. For example, an incorrect gate or valve position, low pressures, and other conditions can cause low conveying velocities. These in turn can cause line plugging. These variables should be monitored so that either an operator or an automatic control system can sense an incorrect situation and take corrective action before major trouble or an unsafe condition ensues.

A control system also provides the interface through which human operators can operate the system. This includes control of motors for driving pumps and crushers as well as control of water valves and ash handling gates.

3.2.4.1 Control System Design

A control system's configuration and design must meet the needs of the operator and the plant operating philosophy, which include locating the control panels and stations and establishing the degree of automation to be used. Another consideration is the operator interface, which includes the amount of information to be presented to the operator and the form in which it is to be presented.

Decisions about who will operate the ash handling system, who will clear problems, and who will maintain the ash handling equipment are critical for determining component and equipment locations, the extent of automation, and the types of panels to be used.

In a small plant, an operator may perform all ash handling system functions, including clearing problems and performing normal maintenance; the operator may also have additional plant duties. In such a case, the main control panel should be located conveniently near the equipment for which the operator is responsible.

The extent of automation is determined by the scope of the operator's duties; that is, the more that the operator must do or watch at one time (including emergency conditions or other cases of temporary overload), the more the controls should be automated. The corollary also is true: if the operator's primary responsibility is to perform ash handling functions, the system should be operated either manually or semiautomatically—both for the operator's well being and because the operator's senses and intelligence are useful adjuncts to control systems and transducers. The continuing activity and responsibility also keep the operator familiar with the process.

A limiting case is the situation in which tedium may cause the operator to become inattentive to plant operations. Most ash handling systems are at least partially automated. Even manual systems include interlocking for most operations.

A complete bottom ash conveying sequence usually takes place in two hours or less, with several jetting nozzle sequence steps and changeovers between hopper sections. Similarly, seal trough and cooling spray header flushing also are within an operator's abilities. Within the bottom ash system, however, monitoring service water pumps is a tedious task that requires constant observation. Because nothing changes while the pumps are operating correctly, the task is too tedious for an operator and should be performed automatically. Most sluice type ash handling systems have logic for automatic operation, with provisions for interlocked manual control that allows the operator to control sequencing optionally.

3.2.4.2 Control Equipment

A control system includes the following:

- Transducers and process switches
- Control panels and local stations, including indicators and controls
- Control logic
- Local controllers, such as local logic and motor controls
- Field actuators, including solenoid-operated air valves, motor-operated valves, and motor-operated pumps

The following information focuses primarily on control panels/stations and the operator interface.

Field control devices for ash handling (except for items in contact with the ash) are quite conventional and include solenoid-operated air valves, cylinders, limit switches, pressure switches, and process transmitters. The exceptions are items exposed to extremely abrasive ash and those within the conveying system water. The pH of the water can vary from acidic to caustic, and the water can contain calcium, sodium, and other substances that can precipitate and foul devices in the system.

Particulate matter can work into pressure switches, causing incorrect operation. As a pressure sensor breathes, contaminants can enter the sensing chamber and be caught, after which they may act like the poppet or ball in a check valve. Gauge isolators should always be used on ash water service for breathing-type transducers, transducers unsuitable for the pH range, or those that will not work wherever silting is likely.

Isolation manifolds with test ports are as important in ash handling as in other process instrumentation, but they must be used with care to avoid the entry of particulates into the manifold, where they can foul the valves.

Field control devices most often are solenoid air-operated gates and valves, motor-driven equipment, and occasionally motor-operated (hydraulic or electric) valves or gates.

Where closer speed control is necessary (such as that required by sluice doors), air-over-hydraulic oil or water glycol systems are used instead of direct pneumatic operation. These applications are found at sluice doors for bottom ash hoppers and dewatering bins. Water-glycol fluid is used at the bottom ash hopper for its fire resistance properties. Its constant viscosity index provides consistent characteristics over a wide range in temperature.

Key Technical Point

Water-glycol fluid is used at the bottom ash hopper for its fire resistance properties. Its constant viscosity index provides consistent characteristics over a wide range in temperature.

Air-operated devices are common in ash handling systems. At locations where compressed air is not readily available or where freezing may be a problem, motor-operated valves or motor actuators are used. Dewatering bins are good candidates for this type of operation. The hydraulic medium chosen in this case must also have a constant viscosity; in addition, some heat tracing may be required.

3.2.4.3 Control Methods

There are many types of ash handling control systems, each with different degrees of complexity. No one method is best for every system or plant. Each case should be reviewed to establish the most suitable selection. Control philosophies that may be applied to ash handling range from simple manual controls to automatic sequencing. A brief description of the alternatives follows.

Direct Manual Operation

The simplest form of control is direct manual operation. In such operation, valves and gates are handwheel-operated; the valve or gate position is observed at the device itself. In small dry bottom ash systems, ash feed into the conveyor may be controlled by the operator raking it into the conveyor intake.

In a direct manual system, motors are controlled with pistol grip or pushbutton switches. Motors are equipped with fuses or circuit breakers to protect both the equipment and the circuit.

Power-Assisted Manual Operation

Power-assisted manual operation is more complex than direct manual operation.

Valves and gates can be equipped with solenoid, cylinder, or motor operators to gain operating speed or to remove some physical burden from the human operator. With power assistance, manual operation can be made remote control quite simply.

Valve or gate operation can be remotely observed using limit switches (located at both ends of gate or valve travel) that operate indicator lights at the remote location. Similarly, pressure and temperature switches can be used to remotely indicate whether process conditions are within or outside their acceptable ranges.

Interlocked Controls

Remote electrical control and position indication make electrical interlocking simple. For example, operation of one valve (B) may be made contingent on the fact that another valve (A) is fully open. Use of such interlocks can limit the operation of a device to only those conditions and situations selected by the system designer.

Automatic Sequencing

With remote electrical control and interlocking available, the next logical step is automatic sequencing. This requires some form of timing along with confirmation of appropriate system sequencing.

3.2.4.4 Environmental Considerations

Control system hardware is affected by its environment, which includes temperature, humidity, dust, moisture, electrical noise, and exposure to mechanical abuse.

Key O&M Cost Point

Control system hardware is affected by its environment, which includes temperature, humidity, dust, moisture, electrical noise, and exposure to mechanical abuse.

Device ratings must be obeyed with respect to these considerations whenever control devices are designed or applied. The alternatives are to design for the environment or to change the environment to suit the equipment used.

Elevated temperatures can affect electrical and electronic equipment in several ways, including the following:

- Thermal runaway in semiconductors or burnout of other devices may result in permanent failure
- Certain electronic operations can be made unpredictable, even if failure is not apparent

Low temperatures can also cause spurious and unpredictable operation.

In both cases, component capacitance and resistance change, as do transistor gains and leakage currents. Resistors have positive temperature coefficients, while semiconductors have negative thermal coefficients. The combinations can make performance of a device unpredictable when operating at temperatures outside its rated range.

If this equipment is installed in a panel, the rating applies to the temperature within the panel where the equipment is actually located. The maximum temperature of any assembled panel must be lower than the inside equipment rating. A typical rating for programmable controllers is 0–60°C (32–140°F). Confirm the internal equipment temperature rating and use it as a limiting design criterion.

Key Technical Point

The maximum temperature of any assembled panel must be lower than the inside equipment rating. A typical rating for programmable controllers is 0–60°C (32–140°F). Confirm the internal equipment temperature rating and use it as a limiting design criterion.

An adequate temperature differential design must be used to transfer the heat through the enclosure to the outside. This keeps the temperature within the housing below the rated maximum temperatures.

Although equipment is designed and rated for high temperatures, trouble-free operation is more likely if it operates below rated temperatures. If an item is rated for operation at 120°F (70°C), it would be proper to use it in a location where the temperature occasionally reached nearly 120°F (70°C) (for example, during the summer months). If the normal temperature, however, is near 120°F (70°C) all or most of the time, the equipment can operate but is likely to have an above normal failure rate. The solution is to install the equipment in a cooler area or provide cooling for the equipment. Cooling can range from simple ventilation to vent fans to air conditioning. Other alternatives include tapping into a plant ventilating duct. For localized hot spots in an equipment enclosure, it might be adequate to install a circulation fan within the enclosure to disperse the heat. Humidity leading to condensation is a particular problem in electronic equipment because it causes high resistance "shorts" or sneak circuits.

Key Technical Point

Humidity leading to condensation is a particular problem in electronic equipment because it causes high resistance "shorts" or sneak circuits.

This can be problematic in electromechanical logic applications but is more problematic in solid-state applications. This is especially true with high voltage switching transients that occur whenever coils are de-energized.

If a humidity problem is expected, enclosure heaters can be added to maintain air temperatures above the dew point. If this causes unacceptably high temperatures, air conditioning or dehumidifying can be used within a panel or for a control room. Electrical and electronic enclosures for industrial use are generally designed to a National Electrical Manufacturers

Association (NEMA) standard that describes the degree of protection that a housing affords or the type of environment in which it may be used.

Care should be taken not to overspecify environmental requirements for an application. Doing so inhibits access to equipment and frequently makes equipment larger than necessary. For example, rather than specifying a NEMA 4 rating for a cabinet that will occasionally be hosed down for cleaning, it would be better to protect the cabinet while it is being cleaned. The NEMA 4 rating requires that multiple clamps be used to hold the enclosure doors shut, rather than a convenient vault handle latch that would be suitable for a NEMA 12 or NEMA 1 application. This exemplifies the kinds of construction changes caused by a change of specification.

The NEMA 4 rating also requires the use of gasketed window covers over some front-mounted items, such as recorders and annunciators. These covers detract from appearance and reliability and impede access to the equipment.

Control room installations should require no protection, and a NEMA 1 general-purpose design should be suitable and most appropriate for both size and accessibility.

The manufacturer's environmental ratings for equipment are of extreme importance, as is experience with that manufacturer's equipment. Suitable spare parts must be stocked based on failure history and availability.

3.2.4.5 Operator Interfacing

Operator interfacing ranges from manually-operated valves and gates, direct reading gauges, sight glasses, and valve position indicators to completely automated systems that are unattended by human operators except to respond to alarm annunciations of abnormal conditions.

Control panels should be located near the equipment and can be simple local stations with a few control switches, panel boards, mimic-type graphic panels, color CRT graphics, or a combination of these. Local stations are used for local maintenance and for clearing abnormal conditions, even in highly automated systems. When manually operating a control panel, the operator should directly observe the effects of his/her actions. Control panels must be designed to benefit the operator and fit into the plant design concept, including cost considerations. Simple interface and visual observation of equipment are critical for operator safety and maximum effectiveness.

Key Human Performance Point

Control panels must be designed to benefit the operator and fit into the plant design concept, including cost considerations. Simple interface and visual observation of equipment are critical for operator safety and maximum effectiveness.

To be of maximum effectiveness, the operator interface must be kept simple and easy to observe.

Indications of critical status that require operator attention or action should be annunciated with both a flashing light and an audible alarm. Operation of an "acknowledge" switch should silence the alarm and change the flashing light indicator to a steady light.

Ash handling systems are automated to remove a burden from operators. The control panels for these systems must not be designed in such a way that returns the burden to the operators by providing excessive numbers of status indicators. An operator should not be given more information or control at a panel than he/she can use directly to operate or dispatch maintenance on the system.

Printers and loggers can be used in these systems to provide a permanent record of status changes, including system alarms. In this way, persistent trouble areas become apparent by showing up frequently.

When used with a higher level programmable controller or computer system, a controller or computer can compare system performance. For example, conveying times for various parts of the system can be compared with normal and past performance to provide early warning of changes and allow preventive maintenance to be performed before a problem worsens.

4
MATERIAL AND EQUIPMENT APPLICATION RECOMMENDATIONS

As confirmed in discussions and correspondence with survey respondents, boiler OEMs, and manufacturers of bottom ash systems and components, a wide variety of materials, designs, and configurations is used to collect, convey, dewater, and dispose of bottom ash from utility boilers. Success rates for a given material or design vary depending on site-specific operating conditions, including bottom ash characteristics and compatibility with other system components.

This section focuses on selecting the most suitable components and products for a particular application. Emphasis is placed on materials of construction based on selection criteria, including the following:

- Abrasion resistance
- Impact resistance
- Corrosion resistance
- Suitability for expected temperature range
- Material cost
- Installation cost
- Maintenance requirements
- Ease of handling
- System configuration
- Possibility of fuel changes
- Operational considerations

Detailed component descriptions, illustrations, and design recommendations are presented in Section 3, and many application issues are described in detail in Section 5. This section is intended for use as a quick reference, providing the reader with key information regarding the application of components and techniques to improve equipment performance and reliability. Adherence to optimized application practices reduces unnecessary burdens on operating and maintenance staff and enables the achievement of long-term savings and equipment and system availability improvements. Where applicable, the discussion includes common system/component misapplications, their causes, and methods for avoiding them. The pros and cons of various component designs are discussed to guide the reader in making appropriate equipment selections.

4.1 Ash Hopper

4.1.1 Refractory

The most significant application issues pertinent to ash hopper refractory are refractory material selection, installation method, anchor spacing, surface preparation prior to refractory installation, and curing of installed refractory.

Key Technical Point

The most significant application issues pertinent to ash hopper refractory are refractory material selection, installation method, anchor spacing, surface preparation prior to refractory installation, and curing of installed refractory.

Common misapplications of refractory are generally the result of inaccurate or incomplete information given to the refractory supplier or a lack of emphasis on the importance of properly drying (and preferably curing) the refractory before boiler operation resumes.

Key Technical Point

Common misapplications of refractory are generally the result of inaccurate or incomplete information given to the refractory supplier or a lack of emphasis on the importance of properly drying (and preferably curing) the refractory before boiler operation resumes.

Refractory material selection is based on the expected severity of the application in terms of impact, abrasion, and thermal shock (quenching). A competent refractory supplier can recommend the optimum material for the known, or expected, operating conditions. Refractories designed for more severe applications are typically lower in cement content, higher in alumina content, and considerably more expensive.

The basic refractory installation methods are gunning, casting, bricking, and ramming. Gunning of refractory in bottom ash hoppers is accomplished by mixing the material in a hopper, from which it is pumped through a nozzle at a velocity sufficient to result in agglomeration on the surfaces of the hopper. Gunning continues until the nozzle operator estimates that the desired final thickness has been applied in all areas. The surface of the finished product has a slightly rough, or beaded, texture. This application method allows installation of the refractory without erecting and removing forms. Material installed in this manner is commonly referred to as *gunnite*.

Casting of refractory requires the erection of suitable forms into which the wet material is placed. Placement of the material can be accomplished by pumping or by carrying it in buckets and dumping it. A minimum setting time of 24 hours (86.4 Ksec) is typically required before the forms are removed.

Key Technical Point

A minimum setting time of 24 hours (86.4 Ksec) is typically required before the forms are removed.

With casting, the surface of the finished product has a relatively smooth texture.

Bricking, as the name implies, involves the setting of vitrified paving bricks in a bed of mortar on top of a concrete fill. Such a paving brick system is sometimes used on the sloped hopper sides, although the monolithic refractories described above are commonly applied to both the vertical and sloped areas of the hoppers.

Ramming is typically used only for small repairs to an existing refractory system. The material is usually placed by hand into the patch location and pounded into place with a hand-held pneumatic reciprocating ram. Materials suitable for this application method are typically supplied in a pre-mixed, ready-to-use condition and are referred to as *rammable* or *plastic* refractories. Optimum anchor spacing can vary for each hopper refractory system, based on considerations such as refractory thickness and hopper configuration. Ash hopper refractory should be a minimum of 9 inches (229 mm) thick, with anchor placement on 15-inch (381-mm) centers (minimum vertical and horizontal).

Key Technical Point

Optimum anchor spacing can vary for each hopper refractory system, based on considerations such as refractory thickness and hopper configuration. Ash hopper refractory should be a minimum of 9 inches (229 mm) thick, with anchor placement on 15-inch (381-mm) centers (minimum vertical and horizontal).

Generally, a system that uses a thinner refractory layer requires closer spacing of the anchors. The refractory supplier typically provides the proper anchors and the installation recommendations.

Preparation of the inside surface of the hopper prior to refractory installation consists mainly of repairing any damaged hopper plate and painting it with two coats of bitumastic asphalt. The asphalt coating effectively separates the refractory from the hopper steel, allowing for differential expansion. For spot repairs to existing refractory, remove any loose material and coat the refractory with the specified binder before hand-packing the patch material and ramming it into place.

Heat curing is accomplished by applying a slow, even heat to the inside of the hopper to dry the refractory and then reaching and maintaining the temperature at which ceramic bonds are formed within the material, greatly enhancing its strength and durability. Firing temperatures of 1,000°F (556ºC) or higher are often required for optimum curing. Gas-fired or electric heaters can be used to apply the heat prior to actually firing the boiler. Adjacent equipment that may be damaged by the elevated temperature must be protected by thermal insulation or temporary removal. In order to avoid the cost and outage impact associated with a true heat-cure, users may simply fire the boiler very slowly on initial startup—using ignition fuel only and minimum air flow—to avoid damage to the new refractory and achieve some degree of bonding within the material.

Key O&M Cost Point

In order to avoid the cost and outage impact associated with a true heat-cure, users may simply fire the boiler very slowly on initial startup—using ignition fuel only and minimum air flow—to avoid damage to the new refractory and achieve some degree of bonding within the material.

4.1.2 Seal Troughs/Plates

Common misapplications include the use of low-alloy steels unsuitable for the operating environment, inadequate provisions for trough flushing, and use of the trough system as an overflow weir for refractory cooling. Although carbon steel is relatively inexpensive and is available as a standard seal trough/plate material from boiler and hopper suppliers, long-term viability in this application is questionable.

Key O&M Cost Point

Although carbon steel is relatively inexpensive and is available as a standard seal trough/plate material from boiler and hopper suppliers, long-term viability in this application is questionable.

The seal trough and plate are subjected to the potentially aggressive environment of the lower furnace, have an inherent gas/water interface, and cannot be repaired without a boiler outage. A potentially aggressive environment makes the use of a suitable stainless steel economically justifiable. Type 316 stainless steel provides good service with extended life, making it an economical long-term choice for seal troughs and plates.

Key O&M Cost Point

A potentially aggressive environment makes the use of a suitable stainless steel economically justifiable. Type 316 stainless steel provides good service with extended life, making it an economical long-term choice for seal troughs and plates.

Flushing must be routine and effective to ensure the flow of water between the seal plate and the bottom of the trough, enabling pressure fluctuations within the hopper to be accommodated by the seal without distortion of the seal plate. The number and placement of flushing nozzles must be adequate to effectively remove accumulated ash from the bottom of the seal trough, ensuring proper operation of the seal and minimizing the possibility of damage. The flushing operation should be automated and performed after each ash emptying cycle or at least once per day during boiler operation. At least one bottom ash system manufacturer offers a “round bottom” trough design to enhance the effectiveness of the flushing operation.

In some hopper designs, the seal trough is used as an overflow weir to provide the water curtain that cools the hopper refractory, protecting it from the radiant heat of the boiler and the detrimental effects of thermal shock. The flow of protective water can be inadequate in some areas due to ash pluggage of the notched weir plate or out-of-level installation. Refractory cooling reliability is greatly improved by the use of a pressurized, punched-pipe system for distribution of the cooling water.

4.2 Ash Transport Piping Systems

Common misapplications generally include the use of piping or components that will not provide long-term, reliable service for the site-specific conditions. A few fundamental piping layout and maintenance practices must also be adhered to in order to avoid operating problems and premature failure.

Although there are a number of piping materials sometimes used for bottom ash sluice systems, the vast majority use hardened cast iron, basalt-lined steel, or ceramic-lined plastic pipe (see Table 4-1). All of these materials are well suited for bottom ash sluicing. Because the choice of piping material is predominantly determined based on short- or long-term cost priorities of the user, piping material selection is more of an economic issue than an application or misapplication issue.

Table 4-1
Common Bottom Ash Slurry Piping Materials

Material	Weight/Unit Length	Hardness	Standard Length	pH Range
Hardened cast iron	60–70 lb/ft (40–47 kg/m)	4.8–6.3 Mohs (~300–500 BHN)	18 ft (5.5 m)	5–9
Basalt-lined steel	70 lb/ft (47 kg/m)	7–8 Mohs (~650–1,000 BHN)	18 ft (5.5 m)	1–13
Ceramic-lined plastic	9.8 lb/ft (6.6 kg/m)	9 Mohs (~1,200 BHN)	30 ft (9 m)	4–12

Any piping components considered for use in the bottom ash sluice system must be designed for abrasive slurry applications in order to provide adequate service life. Although most designers and users are aware of the importance of using appropriate pipe material, it is somewhat more common to use inexpensive knife gates designed for water service, not abrasive slurry service. This misapplication results in leaking or inoperable knife gates, jeopardizing bottom ash system reliability and substantially increasing overall costs. When evaluating materials and components, system designers and users should also keep in mind that leakage from an ash sluice line at certain locations (such as into a public waterway) could result in a violation of environmental regulations.

The considerable turbulence in the piping immediately downstream of an ash pump necessitates adherence to several basic application principles in order to improve system reliability and serviceability. Ash transport piping should be of increased hardness or wall thickness for the first 10 to 20 pipe diameters downstream of the ash pump, including the first and sometimes the second elbow, depending on layout.

Key Technical Point

Ash transport piping should be of increased hardness or wall thickness for the first 10 to 20 pipe diameters downstream of the ash pump, including the first and sometimes the second elbow, depending on layout.

Suppliers of hardened cast iron pipe typically make an extra-hard grade that may be desirable for this area of the system, but it is considerably more expensive and brittle. Basalt is unsuitable for the magnitude of impact experienced in this area and is therefore not recommended. Pipe lined with special alumina corundum or alumina ceramic material usually provides excellent service, as long as the expected ash particle size does not exceed the manufacturer's recommendation. Reinforced gaskets should be used in any fittings or couplings in this area. Isolation valves are sometimes located close to the pump in an effort to facilitate maintenance and minimize the length of pipe that must be drained to service the pump. Even line valves designed for abrasive slurry applications will experience accelerated wear in this section of piping and so should not be located in this turbulent region.

Providers of abrasion-resistant piping materials can assist designers and users in selecting the proper pipe size and the type and location of supports based on the anticipated system pressure, slurry density, and flow rates. Adequate drains and valves should be provided to ensure that each section can be completely drained in a reasonable time and effectively isolated for maintenance. An often overlooked fundamental principle of slurry piping layout is the necessity of using only vertical risers at an increase in elevation.

Key Technical Point

An often overlooked fundamental principle of slurry piping layout is the necessity of using only vertical risers at an increase in elevation.

This practice maximizes the ability of the water to carry the ash particles upward and minimizes the chance that ash particles will drop out of suspension and cause a pluggage. Where the piping decreases in elevation, the process may be performed at an angle other than vertical.

Depending on pipe material and site-specific conditions and routing, cathodic protection may be necessary for sluice systems utilizing metallic pipe. Metallic pipe may also require periodic repainting to minimize the effects of external corrosion or rusting.

4.3 Crushers

Common crusher misapplications include poor access for maintenance, inappropriate shaft seal design, and inadequate shaft seal flush water supply.

Regardless of design specifics and materials of construction, crushers experience considerable wear due to the abrasive nature of the slag and ash being processed. Pluggages or jams occasionally occur and must be manually cleared to enable continued operation and prevent equipment failure. Inefficient combustion within the boiler can result in bottom ash that is difficult to process or an increase in bottom ash quantity, which can increase wear and the likelihood of pluggages. Proper access must be provided to allow personnel to perform routine surveillance, lubrication, adjustments, and maintenance. Suitable rigging points or trolley beams must be provided on overhead structural steel, properly configured and rated for the weight of the heaviest component.

Accessibility to common wear parts should be considered when evaluating crusher designs. Some manufacturers offer hinged access doors to enable replacement of wear parts and clearing of jams without further disassembly of the crusher. If these doors are too heavy, require the removal of too many bolts, or are inconveniently located for the site-specific conditions, their advantage may be reduced. In the absence of such an access door on the crusher itself, it is recommended that an access panel or door be provided near the bottom of the discharge enclosure to allow clearing of jams and inspection of components such as the roll(s) and combing plate.

Each crusher manufacturer has one or more shaft seal designs available, based on considerable research and field-testing. Ruggedness, allowance for expected shaft deflection, sealing effectiveness, and protection of the shaft and adjacent bearing are primary design considerations. Hardened shaft sleeves are recommended for use in the seal areas of the crusher.

Key Technical Point

Hardened shaft sleeves are recommended for use in the seal areas of the crusher.

While this feature will not prevent the initial onset of seal contamination and wear, it will significantly extend the usable life of the seal and confine shaft damage to the replaceable sleeve. A deflector lip or ring should be used between the seal and the adjacent bearing to reduce the possibility of bearing contamination and damage from seal leakage water or ash particles. To maximize the seal protection provided by the packing flush water, an alarm or interlock can be activated by loss of flow or pressure, which will alert personnel to take corrective action before excessive wear or damage occurs. If an adequate supply of potable or filtered water cannot be reliably supplied to the seals at the specified pressure, a flushless seal design should be used.

4.4 Control Systems

Common control system misapplications include the use of inappropriately rated instruments, panels, boxes, and connectors and a component location whose conditions may cause premature failure or an unsafe working environment. All motors, panels, shields, and similar electrical components should be properly grounded to minimize stray voltage problems. Ash system instruments, panels, junction boxes, and connectors should be rated NEMA 4 (waterproof) when located in moist areas.

Key Technical Point

Ash system instruments, panels, junction boxes, and connectors should be rated NEMA 4 (waterproof) when located in moist areas.

Moisture infiltration is one of the leading causes of control system malfunction and failure. Where the ambient conditions are expected to be acidic (often due to sulfurous coal dust), these components should be constructed of corrosion-resistant materials, such as stainless steel or certain plastics. Where ambient conditions are expected to be dry and controlled (for example, in control rooms, cable rooms, and other enclosures), NEMA 1 rated components are adequate, less expensive, and less cumbersome.

Known or expected ambient temperatures must be taken into account during the selection of instruments and other control system components. The user needs to be sure that equipment ratings are adequate for any anticipated environmental conditions. Care should be taken to ensure that equipment and the conduit are not located or routed near hot spots, such as boiler floor steel or upper hopper steel.

Proximity to equipment and fundamental safety principals must also be properly balanced when locating bottom ash system local control panels. From an operating standpoint, it is advantageous, and sometimes essential, to have local control panels positioned such that the operator can observe the equipment being controlled. From a safety standpoint, it is essential that local panels not be located where the operator would be harmed if a malfunction were to occur. For instance, if access doors are provided in the lower area of the discharge enclosures, the local control panel must be located at a safe distance and elevation in case of a door closure failure while the discharge gate is open.

4.5 Dewatering Systems

The most common misapplications associated with dewatering bins, settling tanks, and surge tanks typically fall into the category of underestimating the importance of conservative design as it relates to number of bins/tanks, size of bins/tanks, cone slopes, and recommended features. Environmental considerations must also be taken into account.

Two or more dewatering bins should be used in order to allow adequate volumetric margin, to provide the necessary flexibility for filling, dewatering, and unloading cycles, and to allow for planned or corrective maintenance. Size the dewatering bins for a combined net storage capacity representing 72 hours (260 Ksec) of production of bottom ash at MCR.

Key Technical Point

Size the dewatering bins for a combined net storage capacity representing 72 hours (260 Ksec) of production of bottom ash at MCR.

A discharge skirt and underflow baffle should be provided for each bin. To ensure effective emptying of ash, the cone angle should be 55 to 60 degrees (0.96 to 1.0 radians) from the horizontal, and brackets should be provided for mounting four vibrators at 90-degree (1.6-radian) intervals.

Key Technical Point

To ensure effective emptying of ash, the cone angle should be 55 to 60 degrees (0.96 to 1.0 radians) from the horizontal, and brackets should be provided for mounting four vibrators at 90-degree (1.6-radian) intervals.

Depending on bin diameter, one or two vibrators should be provided as original equipment. In cold climates, thermostatically controlled freeze protection should be provided for the drain lines and valves as well as the lowest portion of the cone.

The settling tank should be sized such that the rise rate of the water is less than the settling velocity of the particles that are expected to be handled. To ensure that settled-out sludge can be effectively removed, the cone angle should be 45 degrees (0.78 radians) from the horizontal.

Surge tank size is determined by the collective volume of the rest of the dewatering system. The surge tank should be able to store all of the water used in the system and release it as needed. A cone angle of 35 to 45 degrees (0.61 to 0.78 radians) is recommended. The height of the surge tank is determined by several performance factors, including the provision of positive suction head for the pumps and an adequate dead band for level control. The amount of dead band required is affected by the degree of turbulence expected and the type of level controllers being used.

Detailed sizing and design recommendations are presented in Section 3.1.9 and are not repeated here. Designers and users must also keep in mind that any change in coal usage—especially a switch to a fuel with higher ash content, lower heating value, or both—will significantly affect the dewatering system operation and adequacy.

As is the case throughout the plant site, provisions must be made for the proper treatment of any dewatering system leakage or effluent before it is discharged in order to avoid violation of environmental regulations.

4.6 Discharge Gates/Doors

Most discharge gates are well designed for the harsh, abrasive service involved in sluicing the ash slurry from hoppers and discharging dewatered ash from bins. Misapplications occasionally occur when material selection is based on short-term savings rather than long-term reliability. In general, all wear parts of the bottom ash sluice gates and doors should be made of a suitable stainless steel (typically type 316 stainless).

Key Technical Point

In general, all wear parts of the bottom ash sluice gates and doors should be made of a suitable stainless steel (typically type 316 stainless).

Gate faces are sometimes made of rubber, which initially provides a more leak-free seal than stainless steel but is more susceptible to abrasion and cutting by jagged ash and slag. Depending on site-specific conditions and priorities, rubber faces may provide adequate service, but stainless steel is recommended for most applications.

In an effort to minimize leakage with stainless steel gate faces, more than one supplier of heavy-duty ash gates has recently incorporated “support wheels” into the closing system, which enable increased sealing pressure around the hopper opening in comparison to wedge blocks alone. This feature is worthy of consideration by the user or designer.

4.7 Pumps

4.7.1 Centrifugal Pumps

Common misapplications for centrifugal ash pumps include choice of liner material, sizing of impeller clearances, and selection of drive mode. Heavy-duty slurry pumps are often provided with or without wear liners, and liner materials are most often made of rubber or cast iron. The characteristics of the slurry determine whether wear liners are required and the best choice of liner material.

The abrasive, jagged nature of bottom ash necessitates wear liners and limits the choice of material. Rubber-coated impellers and rubber wear liners are occasionally used in bottom ash pumps but generally provide inadequate wear life. Impellers and wear liners of centrifugal pumps made of high chrome, hardened cast iron provide the best resistance to degradation and therefore the best value.

Key Technical Point

Impellers and wear liners of centrifugal pumps made of high chrome, hardened cast iron provide the best resistance to degradation and therefore the best value.

The expected sizing output of the crusher must be taken into consideration during design or selection of the jet pump. Throat clearance must be at least twice the size of the largest ash particles expected to be passed by the crusher. Pluggage of the throat may be caused by a crusher that has a spring-release feature, which allows it to pass hard clinkers or tramp oversized material.

Direct-coupled and belt drive models are available for heavy-duty slurry pumps. Belt drives are less expensive and easier to align and maintain. Due to the complexity of bottom ash systems, it is not unusual for impeller adjustments to be required during initial startup testing or after any changes are made to the system. Performing such adjustments (fine-tuning) on direct-coupled pumps is difficult and expensive but is relatively simple and inexpensive for belt driven models. Belt drives are the best choice for centrifugal bottom ash pumps.

Key Technical Point

Belt drives are the best choice for centrifugal bottom ash pumps.

4.7.2 Jet Pumps

Although jet pumps are relatively inefficient, they are often chosen for ash sluice systems because they are simple, rugged, and inexpensive. Common misapplications for jet pumps relate mostly to material selection, accessibility for maintenance, sizing of throat clearance, and system requirements for developed head.

For most bottom ash systems, high chrome or nickel-chrome alloys provide the best service life for combining tubes and tailpieces. Nozzles are commonly made of a hardenable grade of stainless steel, which provides good service. If ash particles or other abrasives are present, or expected to be present, in the nozzle water, more abrasion-resistant nozzles, typically made of tungsten carbide or ceramic, can be used.

Jet pumps contain no moving parts and are constructed such that the common wear parts (nozzle, combining tube, and tailpiece) can be easily removed, inspected, and replaced as needed. Suitable galleries and rigging points should be provided to allow safe and efficient inspection and service of the jet pumps. Ejectors are not suitable for pump head requirements of more than 150 feet (45.6 m).

Key Technical Point

Ejectors are not suitable for pump head requirements of more than 150 feet (45.6 m).

4.8 Mechanical Bottom Ash Systems

The most common misapplications for MBASs fall into the categories of material selection, accessibility for maintenance, and dewatering slope angle. Bottom ash chains should be top quality, case hardened, and annealed to achieve a hard wear surface (550–800 BHN [~6.75–7.6 Mohs]). Abrasion-resistant steel, such as AR400, is commonly used for abrasive wear.

Key Technical Point

Bottom ash chains should be top quality, case hardened, and annealed to achieve a hard wear surface (550–800 BHN [~6.75–7.6 Mohs]). Abrasion-resistant steel, such as AR400, is commonly used for abrasive wear.

If abrasion is expected to be particularly severe, covering wear surfaces with ceramic or basalt tile can be effective and result in long-term savings.

Subcomponents that require routine inspection, lubrication, adjustment, and maintenance include the conveyor chain and flights, chain drive, idlers, and sprockets. Access panels and suitable galleries must be provided to allow safe and efficient inspection, adjustment, lubrication, and repairs.

To ensure that ash will be effectively conveyed up the dewatering slope without cascading back into the bend area and causing pluggage, the slope angle should generally not exceed 30 degrees (0.52 radians) from horizontal.

5 MAINTENANCE

Because bottom ash systems operate under extremely harsh conditions and are critical to boiler operation and availability, a disproportionate amount of maintenance is required to keep them operating reliably. These same factors have resulted in a proliferation of specialized materials, techniques, and designs that address the most common failure modes.

5.1 Common Failure Modes and Mitigation Recommendations

Based on failure descriptions and data gathered from users and manufacturers, common failure modes for each component are identified and briefly discussed in this section. Mitigation recommendations focus on identifying failure mechanisms and utilizing the methods, materials, and modifications that have provided long-term solutions to these problems within the industry. This section is intended for use as a quick reference, summarizing key points and best practices as identified by surveying numerous users, manufacturers, and vendors during the investigative phase of producing this guide. Detailed component descriptions and illustrations are presented in Section 3, and many failure modes and mitigation techniques are described in Section 5.2.

Formal root cause analysis and detailed investigation of specific equipment failures are not within the scope or intent of this guide. Therefore, the discussion in this section is brief and general, focusing on the most common causes of the described failures and recommendations that are helpful in mitigating each failure mode. It is incumbent on the equipment user to correctly identify the cause of any specific problem so that it can be properly addressed using the methods described in this guide. Recommendations are examples of techniques that have been successfully used to solve the problems being discussed. Applicability of any recommended solution must be determined on a case-by-case basis by personnel familiar with site-specific equipment details.

5.1.1 Ash Hopper

5.1.1.1 Refractory

The refractory system on bottom ash hopper walls and slopes can be affected by several failure modes, including impact damage, cracking or spalling, erosion, and corrosion.

Impact damage most commonly occurs when large pieces of slag or sintered ash fall into the hoppers. It can also be caused by falling tramp metal, such as tube shields or spacers. The top of the slope walls (which separate adjacent hoppers) is the most vulnerable location because protection by the impounded water is at a minimum and falling objects can strike a direct, rather than glancing, blow.

- Contact the furnace and/or sootblower supplier for assistance in minimizing slag/ash falls from the boiler tubes.
- If tramp metal is a significant problem, the source must be identified and proper corrective action taken elsewhere in the boiler. For instance, if tube shields or spacers commonly fall into the hoppers, then improving the attachment design or installation method will minimize detachment of these components from the boiler tubes. In some applications, it may be advantageous to replace tube shields with spray metallizing.
- Substantial metal guards (often referred to as *cricket guards*) can be fabricated and installed at the top of the slopes and embedded in the surrounding refractory. This arrangement allows the energy of falling objects to be distributed over a wider area and provides an impact surface that is much less susceptible to fracture. Depending on the chemistry of the ash hopper water and the lower boiler atmosphere, stainless steel guards may provide longer service life.

Cracking or spalling primarily occurs due to the inherent thermal cycling in the bottom ash hopper environment. These effects can be exacerbated by common operational problems.

If any portion of the hopper wall refractory loses the protective coverage of the water curtain, it will be alternately heated and quenched, which accelerates cracking and spalling.

- Keep sediment accumulations flushed out of the curtain water supply piping or troughs
- If a water curtain is provided by a trough, consider upgrading to a punched pipe system for improved coverage and reliability.

Erosion is unavoidable and occurs due to the turbulence produced by the flushing nozzles and the sliding abrasion of the ash. It is usually most pronounced on the hopper slopes. Excessive erosion of ash hopper sides can be caused by misaligned flushing nozzles or flush water pressure exceeding the manufacturer’s recommendations.

Key Technical Point

Excessive erosion of ash hopper sides can be caused by misaligned flushing nozzles or flush water pressure exceeding the manufacturer’s recommendations.

Carbon monoxide in the lower boiler atmosphere or low pH of hopper water can cause corrosion in refractory. If there is a problem of refractory corrosion, plant personnel must accurately determine the operating conditions and identify the corrosive agent.

- A competent refractory design company can then be consulted to determine if a suitable refractory composition is available, which would be more resistant to the specific corrosion mechanism.
- Alternately, treatment of the sluice water system with a buffering chemical may be preferable because all wetted components in the sluice system would be protected.

Personnel can also cause localized refractory damage when poke bars are used to remove ash bridging or slag accumulations from the slag tap of a wet bottom (slagging) furnace. Damage of slag tap refractory can result in rapid erosion of floor tubes in the tap and subsequent tube leaks.

Key Technical Point

Damage of slag tap refractory can result in rapid erosion of floor tubes in the tap and subsequent tube leaks.

Adequate training in the proper method of rodding taps and the precautions that must be observed can minimize tube damage.

Industry best practices that have proven to mitigate all of the above failure modes include the following:

- Addition of stainless steel fibers to the gunnite or castable refractory mix (commonly 2% by weight) before installation on the hopper walls or slopes. The fibers stabilize the monolithic refractory and reduce the tendency of cracked or spalled pieces to detach.
- In cases where it can be installed without prohibitive expense or interference with other outage activities, heat-curing the hopper refractory can improve service life by baking out the inherent moisture and establishing ceramic bonds within the material. A heat cure of this scope and complexity should be performed only by an experienced contractor, with suitable protection of adjoining structures and equipment.
- Maintaining hopper water level while pulling ash.

5.1.1.2 Seal Troughs/Plates

The water-filled trough and plate system that provides the seal around the boiler bottom can be affected by several failure mechanisms. The primary cause of damage is corrosion due to the aggressive nature of boiler gasses and the inherent gas/water interface. Due to the lack of on-line accessibility for repairs, resolution of problems usually involves the use of corrosion-resistant materials.

- Several grades of stainless steel can be considered for fabrication of replacement plates and troughs. Site-specific corrosion mechanisms will dictate the best alloy choice. See Section 4, “Material and Equipment Application Recommendations,” for more details on corrosion-resistant alloys. A polymer coating on the hopper plates and seal troughs will resist corrosion and elevated temperatures.

Key Technical Point

A polymer coating on the hopper plates and seal troughs will resist corrosion and elevated temperatures.

- If an owner is considering such a polymer coating approach, several competent coating manufacturers should be consulted for a thorough analysis and recommendation.

- At least one manufacturer offers a “round bottom” seal trough, which is designed to improve the effectiveness of the flushing operation. Users might consider this option when assessing ash hopper design or retrofits, especially if seal trough flushing has been a problem.

5.1.2 Ash Transport Piping Systems

Primary failure mechanisms affecting ash transport piping systems include erosion, corrosion, and impact. Undercutting of abrasion-resistant liners can also occur. Erosion of piping system components occurs due to sliding abrasion from the ash slurry being conveyed. Periodically rotating straight lengths of ash piping in each ash conveyor pipeline is an excellent technique for extending pipe life.

Key Technical Point

Periodically rotating straight lengths of ash piping in each ash conveyor pipeline is an excellent technique for extending pipe life.

- To determine the appropriate frequency of rotation, a few straight lengths on each pipeline should be visually inspected for wear, either on a scheduled basis or during normal maintenance activities. This can be most easily performed by removing an elbow in an accessible location. Wear on the upstream straight length will be more representative of the wear throughout the piping system because both the location and severity of abrasion on the downstream straight length will be affected by the flow disturbance from the elbow. Comparing the percentage of wall loss to the time in service allows an estimate of the wear rate. Most erosive wear occurs in the bottom quadrant of the piping. Based on the estimated wear rate, rotations should be scheduled to occur when the pipe wall or abrasion-resistant liner is expected to be approximately 50–75% worn in the bottom quadrant. Rotations are typically done in increments of 90 or 120 degrees (1.6 to 2.1 radians). If adequate for the wear pattern, 90-degree (1.6-radian) rotations are preferred because three rotations can be performed before the pipe enters its final wear cycle.

Erosion is more prevalent at fittings, where directional changes and/or turbulence may occur.

- In unlined metallic piping systems, integral wearbacks (increased wall thickness) are often incorporated at the high-wear areas of fittings.
- Most piping system manufacturers offer optional fittings constructed of more abrasion-resistant materials than the straight lengths. The increased cost of such fittings is usually justified by the increase in service life.
- Instead of discarding fittings that have experienced localized wear, in many cases the worn areas can be rebuilt with an abrasion-resistant epoxy and the fittings stocked for reuse. A variety of ceramic-filled and carbide-filled epoxies is available for this application-specific recommendation; installation instructions can be obtained from epoxy manufacturers or vendors.

At some plants, low pH of the sluice water can cause corrosion of the ash piping components. In these (somewhat uncommon) situations, plastic piping or piping lined with basalt or ceramic will generally be much more impervious to chemical attack.

Impact damage to the inside of ash piping most commonly occurs in the pipe and fittings closest to an ash pump, including the first elbow after the pump and the elbow at the top of the riser where the ash pipe emerges from a pit or trench.

- Most manufacturers of ash piping offer impact-resistant pipe and fittings. Depending on the system layout, impact-resistant pipe and fittings are recommended for the first 10 to 20 pipe diameters downstream of the ash pumps. A high-impact-resistant lining, such as alumina ceramic or alumina corundum, is used in unlined high chrome metallic pipe in areas closest to the ash pump, including the first downstream elbow.

Key Technical Point

A high-impact-resistant lining, such as alumina ceramic or alumina corundum, is used in unlined high chrome metallic pipe in areas closest to the ash pump, including the first downstream elbow.

Undercutting of abrasion-resistant liners is usually caused by improper alignment at pipe connections. Manufacturers of lined pipe have developed components and methods that ensure proper alignment when used correctly during installation.

- The installer of the piping system must use the proper components and techniques.

5.1.3 Crushers

Primary failure mechanisms affecting crushers include erosion, corrosion, binding, and shaft seal failure. Erosion of the roll(s) and wear plates occurs due to the abrasive nature of the ash being crushed. Rolls and wear plates are made of hardened cast alloys for maximum resistance to wear.

Some manufacturers offer symmetrical, reversible roll segments and wear plates, which can be unbolted and reversed at their half-life to extend the interval between required crusher overhauls. A cost-saving best practice is to rebuild crusher rolls rather than replace them when they have worn beyond the manufacturer's specification.

Key O&M Cost Point

A cost-saving best practice is to rebuild crusher rolls rather than replace them when they have worn beyond the manufacturer's specification.

These rebuilds can be completed on site by plant personnel, in accordance with manufacturer's instructions, or the rolls can be sent to the manufacturer for rebuilding. One or more sets of rolls (new or rebuilt) and other common wear parts should be kept on site to ensure a quick turnaround in the case of crusher maintenance.

Corrosion of crushers occasionally occurs due to low pH of the ash hopper water or the damp, acidic ambient conditions that can exist in the ash pit below a boiler. Rolls and wear plates are usually not significantly affected, and material selection for these parts is restricted by the overriding need for wear resistance. For special circumstances where corrosion is a significant problem, casing and frame components are available in stainless steel.

Binding of crushers generally occurs due to 1) overloading or 2) tramp material of some kind, such as detached wall or slope refractory, tube shields, or tube spacers.

If binding is due to overloading, an operational assessment must be performed to determine the cause.

- Inefficient ash pump operation can cause recirculation of ash in the crusher. Make sure the ash pump is capable of sluicing the ash at a faster rate than the crusher processes it.
- Inadequate dilution water flow at the bottom of the ash hopper can result in slurry that is too concentrated for the crusher and/or the ash pump. Ensure that there is adequate dilution flow and that ash is slurried before opening the sluice gate.
- If binding is due to the normal ash loading and hardness typical for the boiler, an upgrade of the motor or the entire crusher may be required. Check with the crusher manufacturer regarding the feasibility of installing a larger motor. If the existing crusher is not suitable for use with a larger motor, it may be necessary to upgrade the entire crusher/motor assembly, in which case several brands and designs should be considered based on site-specific operating conditions and maintenance experience.
- If binding is due to tramp material, the source must be identified and proper corrective action taken elsewhere in the boiler. For instance, if tube shields or spacers commonly fall into the hoppers, then improving the attachment design or installation method will minimize detachment of these components from the boiler tubes. In some applications, it may be advantageous to replace tube shields with spray metallizing. If detached refractory is a significant cause of crusher binding, the refractory must be investigated and appropriate repairs or replacement performed. Crushers are designed to reduce detrimental effects of binding by using auto-reverse or spring release of the roll(s). A disadvantage is the potential for problems with oversized material in the ash pumps.

Key Technical Point

Crushers are designed to reduce detrimental effects of binding by using auto-reverse or spring release of the roll(s). A disadvantage is the potential for problems with oversized material in the ash pumps.

Shaft seal failure is commonly caused by shaft deflection, dirty or inadequate seal flush water, and improper adjustment or lubrication. Seal failure can damage the crusher shaft and bearings and, in severe cases, result in an accumulation of water and ash below the crusher. Crusher shaft sealing is such a significant problem for users that crusher, seal, and packing manufacturers have designed an enormous variety of products and features to address it. The following information highlights the primary failure modes and the general approaches for mitigation.

Due to the high forces required to effectively crush the bottom ash, shaft deflection is a common operating characteristic of crushers. Excessive deflection results in eccentric rotation of the shaft, making it very difficult to seal. Crusher manufacturers attempt to minimize this deflection in a number of ways, including mounting the shaft bearings directly to the crusher frame or using a square shaft cross-section within the crusher.

The most common seal design uses several rings of packing and a perforated lantern ring to allow clean flush water to enter the packing gland. Ideally, the flush water should be of potable quality and supplied to the gland at the pressure stated on the system drawings or approximately 5 psi (34.5 kPa) above the maximum static head in the hopper.

- Flush water that contains dirt, ash, sludge, or other similar impurities can introduce particles into the gland, which can embed on the surface of the packing rings and abrade the shaft. If potable water is unavailable for flushing the seal, a fine-mesh duplex strainer can be installed to provide suitable filtration before the water enters the gland. This approach demands proper operation, flushing, and maintenance of the strainer to ensure protection of the seal.
- In cases where it would be impractical to provide flush water of suitable pressure and cleanliness, seal designs that require no flush water are available.

Any type of seal will fail if it is not properly installed, adjusted, and lubricated.

- As packing wears or consolidates, the packing gland follower must be gradually and evenly tightened until only a small amount of seal water flows out of the gland. Overtightening can cause the packing to act as a brake on the shaft, which will increase shaft wear, possibly contributing to binding of the crusher.
- In the case of flushless, pumpable packing systems, the gland must be periodically pumped up with grease or packing compound, depending on the design of the seal system. Manufacturers of such systems offer simple accessories that automatically inject the proper grease or compound as needed. The best practice for problematic crusher seal applications is to use a hardened shaft sleeve in the seal areas.

Key Technical Point

The best practice for problematic crusher seal applications is to use a hardened shaft sleeve in the seal areas.

The sleeve can be made of tool steel or another suitable material, depending on the application. Although this approach addresses a seal failure symptom rather than root cause, it is relatively economical and can significantly extend the life of the seal and shaft.

5.1.4 Control Systems

Primary failure modes affecting bottom ash handling control systems include corrosion or shorting of wiring, connections, and other components due to the moist, sometimes acidic, ambient conditions common in the ash pit and elsewhere in the plant. High ambient temperatures can also shorten the life of electrical insulation and electronic components.

- NEMA 4X waterproof instruments, junction boxes, control panels, and connectors should be used in the ash pit area and in other parts of the plant where moisture can be expected. Stainless steel boxes and panel components are especially well justified in the ash pit area.

- If casing leaks or deteriorated insulation on hot equipment causes high ambient temperatures, the leaks or insulation should be repaired for the benefit of all equipment and personnel in the area. If high ambient temperatures are unavoidable, the control system components in such an area must be adequately ventilated, cooled, or relocated.

5.1.5 Dewatering Systems

Primary failure modes affecting dewatering bins, settling tanks, and surge tanks include erosion, impact, and corrosion, with erosion and impact wear almost always confined to the slurry entrance area of the dewatering bins. This is where impact plates or grates are located and designed specifically to resist wear and dissipate the energy of the entering ash/water mixture. The impact plates/grates are also designed and oriented to evenly distribute the flow to the bin below. These plates/grates are typically constructed of wear-resistant high-chrome alloys. Periodic inspections for wear and structural integrity normally allow adequate time for planned repair or replacement during an outage, if the need should ever arise. Although rare, erosion sometimes occurs in the lower cone area of the dewatering bins as a result of sliding abrasion during the emptying process. If this is a problem at a particular plant, the economics of replacing the lower cone with stainless steel can be evaluated.

Corrosion of bins and tanks in the dewatering system occasionally occurs on the exterior if dirt, coal dust, or ash is allowed to accumulate on the surface, especially in a damp location. Normal cleaning and painting should ensure that this type of corrosion is a non-issue.

5.1.6 Discharge Gates/Doors

Primary failure modes affecting discharge gates include erosion and corrosion. Erosion of the gate face, seals, liners, breaker bars, guide angles, rollers, supports, and braces inevitably occurs due to the abrasive nature of the ash/water mixture being slurried. Mitigation of erosion in discharge gates consists mainly of using abrasion-resistant components and linings and consistently employing proper operating techniques.

If the nozzles used for slurrying operate for too long a time before the discharge gate is opened, the turbulence can increase erosive wear on the face of the gate. Refer to the system instructions for the correct slurrying procedure.

5.1.7 Pumps

5.1.7.1 Centrifugal Pumps

Primary failure modes affecting centrifugal pumps in bottom ash systems include erosion, corrosion, lubrication failure, and belt drive failure. Erosion of impellers and casings inevitably occurs due to the abrasive nature of the ash/water mixture being pumped. In pumps designed for slurries, abrasion-resistant linings are commonly used on the impellers and casings. Due to the hard, jagged nature of bottom ash particles, elastomer linings (although less expensive) often provide poor service. Mitigation of erosion in bottom ash slurry pumps consists mainly of using impellers and casing liners that are cast from extremely hard alloys, such as 27% chrome or Ni-Hard.

> **Key Technical Point**
>
> **Mitigation of erosion in bottom ash slurry pumps consists mainly of using impellers and casing liners that are cast from extremely hard alloys, such as 27% chrome or Ni-Hard.**

Corrosion of these pumps is rare because the alloys required for erosion protection are also very corrosion resistant.

Lubrication failure can be caused by a number of factors, including the entry of water into the bearings, underlubrication, and overlubrication. If water is found in a pump bearing during normal inspection activities or if evidence of water (for example, rust) is found in a failed bearing, the source of the water must be identified and the problem corrected. Excessive packing leakage can often spray enough water on an adjacent bearing to cause infiltration. Packings should be routinely monitored, adjusted, and maintained to help avoid bearing damage.

The proper amount of the correct lubricant must be kept in the bearings at all times. Literature from the pump manufacturer will specify the proper lubricant and lubrication techniques for the specific application. In the absence of such literature, the necessary information can be obtained from the pump or bearing manufacturer.

Belt drive failures most commonly occur due to misalignment or improper belt tension. A simple straightedge alignment of the drive pulley and driven pulley is adequate. Simple, effective belt tensioners are normally provided by belt vendors.

5.1.7.2 Jet Pumps

Primary failure modes affecting jet pumps in bottom ash systems are erosion, impact, corrosion, and lubrication failure.

Erosion and impact of combining tubes and tailpieces inevitably occurs due to the abrasive nature of the ash/water mixture being pumped and the localized turbulence. Mitigation of erosion and impact in bottom ash jet pumps consists mainly of using components that are cast from extremely hard tough alloys, such as 27% chrome or Ni-Hard.

> **Key Technical Point**
>
> **Mitigation of erosion and impact in bottom ash jet pumps consists mainly of using components that are cast from extremely hard tough alloys, such as 27% chrome or Ni-Hard.**

Ceramics have generally not provided an erosion solution for combining tubes and tailpieces because they lack the toughness required to withstand the impact forces.

Nozzle erosion can be caused by abrasive impurities in the high-pressure ash sluice water. If nozzle erosion is a significant problem, contact the manufacturer to obtain appropriate ceramic nozzles, which will give maximum wear life in the presence of abrasives.

Corrosion of these pumps is rare because the alloys required for erosion protection are also very corrosion resistant. Because they are commonly made of more conventional alloys, pump bodies will occasionally suffer corrosive attack due to low-pH water in the system. Various grades of stainless steel can be used to fabricate pump bodies to minimize this problem.

5.1.8 Mechanical Bottom Ash Systems

Primary failure modes affecting MBASs include impact, erosion, and corrosion. Impact damage most commonly occurs when large pieces of slag or sintered ash fall into the ash tank. If impact damage is a significant problem, contact the furnace and/or sootblower supplier for assistance in minimizing slag/ash falls from the boiler tubes.

Erosion of moving parts within the MBAS is a result of the abrasive nature of the material being received and conveyed. Mitigation consists of using extremely hard alloys, cast basalt, or ceramics at known wear points. Chrome-nickel alloys and case hardening are commonly used for chain links of MBAS, achieving surface hardness in the range of 550–800 BHN (~6.75–7.6 Mohs).

Key Technical Point

Chrome-nickel alloys and case hardening are commonly used for chain links of MBAS, achieving surface hardness in the range of 550–800 BHN (~6.75–7.6 Mohs).

Conveying trough bottoms, wear strips, and flight bar wear surfaces can be fabricated from abrasion-resistant steels (such as AR 400) or covered with basalt or ceramic tile. MBAS components with corrosion problems can be replaced with stainless steel fabrications; however, it is preferable and more economical to control pH by injecting appropriate chemicals at the surge tank.

Key Technical Point

MBAS components with corrosion problems can be replaced with stainless steel fabrications; however, it is preferable and more economical to control pH by injecting appropriate chemicals at the surge tank.

5.2 Preventive Maintenance and Replacement Guidelines

This section provides recommendations for an effective, proactive maintenance program. It gives detailed information for choosing the best replacement or upgrade components for a given application based on industry best practices as determined by survey responses and follow-ups along with manufacturer literature and input. Information is provided regarding lubrication, operational inspections, and outage inspections for the basic major subsystems. The components, subsystems, and systems discussed are described in detail in Section 3.

Basic preventive maintenance recommendations for ash handling systems are outlined, including actions to be taken on daily, weekly, monthly, and quarterly schedules and during scheduled outages. The procedures described are generic; that is, the information given for the discharge doors of bottom ash hoppers also applies to the discharge doors of dewatering bins and other tanks.

This information is intended to provide general insight into the requirements of commonly used equipment. It should be used in conjunction with the specific information provided by vendors. In determining the necessity or appropriate frequency of any inspection or maintenance activity, there is no substitute for the judgment of experienced and conscientious plant personnel. Attentive, observant, and conscientious plant personnel are the key to an effective maintenance program.

Key Human Performance Point

Attentive, observant, and conscientious plant personnel are the key to an effective maintenance program.

Preventive maintenance recommendations given in this guide and in manufacturer's literature are not meant to replace the observations and experience of staff members who are intimately familiar with the equipment. Inspection and preventive maintenance activities should be adjusted and optimized at each site based on plant records and expertise. Long periods of unusually low or high electrical generation may also necessitate adjustments in preventive maintenance activities. Thorough documentation and tracking of inspection reports and component failure histories is essential for maintenance optimization.

The maintenance information presented in this guide is divided into the following subsections that describe work on major systems:

- Hydraulic bottom ash systems
- Recirculating water systems
- Mechanical bottom ash systems

The discussion of each topic is intended to be complete within itself. Consequently, some information is duplicated because it applies to more than one subsystem or situation. For example, some actions appear in descriptions of both operational inspections and outage inspections. Certain information is deliberately repeated to minimize the need for "page flipping" by a reader who is following a specific discussion.

5.2.1 Hydraulic Bottom Ash Systems

Whenever performing any work or inspections in the bottom ash hopper or on the equipment used in the bottom ash system, it is essential to observe all plant safety rules.

Key Human Performance Point

Whenever performing any work or inspections in the bottom ash hopper or on the equipment used in the bottom ash system, it is essential to observe all plant safety rules.

Review the supplier's instruction manuals for safety precautions concerning specific items of equipment before undertaking work with such equipment.

5.2.1.1 Lubrication

Table 5-1 summarizes the lubrication requirements for bottom ash and mill rejects systems. The table can be used to develop checklists for lubrication at required intervals for each component.

Table 5-1
Lubrication Items: Bottom Ash and Mill Rejects Systems

Item	Frequency of Lubrication			
	Daily	**Weekly**	**Monthly**	**Quarterly**
Compressed-air lubricators	X			
Crusher drive			X	
Crusher drive-gear motor/drive change lubricant				X
Crusher seals and bearings			X	
Dewatering bin drip pan bearings		X		
Dewatering bin floating decanter unit			X	
Line gates/valves, bearings		X		
Line gates/valves, packing			X	
Level detectors/dewatering bins			X	
Mechanical pump drives			X	
Mill rejects hopper inlet gate			X	
Mill rejects hopper transfer-tank gate			X	

5.2.1.1.1 Compressed-Air Lubricators

Compressed-air lubricators should be inspected daily and refilled to the specified level.

5.2.1.1.2 Crusher Drive

The oil level in the crusher drive should be checked monthly and refilled to the specified level if it is low.

Lubricants for a crusher motor and drive should be changed either on the cycle shown in the supplier's instructions or quarterly (in the absence of such instructions). Use the proper lubricant for the ambient temperature conditions.

Crusher seals and bearings should be lubricated with the recommended lubricants.

- Do not overlubricate the seal. Overlubrication can lead to a braking effect on the shaft, which can cause overheating and/or crusher stalling.

5.2.1.1.3 Dewatering Bin Drip Pan

If the unit bearings have grease fittings, the bearings should be lubricated weekly. Refer to the supplier's drawings for locations of the lubrication fittings.

5.2.1.1.4 Dewatering Bin Floating Decanter Unit

If the unit has bearings with grease fittings, the bearings should be lubricated monthly. Refer to the supplier's drawings for locations of the lubrication fittings.

5.2.1.1.5 Line Gates/Valves

The bearings should be lubricated weekly with the recommended lubricant.

If any gates or valves use packing, the packing should be lubricated as specified on the drawings or in the instructions. If there are no instructions, the packing should be lubricated monthly.

5.2.1.1.6 Level Detectors/Dewatering Bin

If level detectors are used on the dewatering bins or in a slag tank, they should be lubricated monthly with the recommended lubricant.

5.2.1.1.7 Mechanical Pump Drives

Bearings and other items of mechanical pump drives requiring lubrication should be lubricated either weekly or monthly, as recommended in the supplier's instructions.

5.2.1.1.8 Mill Rejects Hopper

The inlet gates of a mill rejects hopper should be lubricated monthly if they have a lubrication fitting. The supplier's drawings should show the location of the fittings.

5.2.1.1.9 Mill Rejects Transfer Tank Gate

The inlet gates of a mill rejects transfer tank should be lubricated monthly if they have a lubrication fitting. The supplier's drawings should show the location of the fittings.

5.2.1.2 Operational Inspections

Table 5-2 summarizes the required inspections, and their frequencies, to be performed on hydraulic bottom ash and mill rejects systems during plant operation. This table can be used to develop checklists for periodic inspections of the various components. Sections 5.2.1.2.1 through 5.2.1.2.29 provide supplementary information on the inspections.

Table 5-2
Operational Inspections: Bottom Ash and Mill Rejects Systems

Item	Frequency of Inspection			
	Daily	Weekly	Monthly	Quarterly
Air cylinders/leakage			X	
Air cylinders/operation			X	
Ash hopper discharge–gate enclosure/leakage			X	
Ash hopper discharge–gate/leakage			X	
Ash hopper overflows/temperature		X		
Ash hopper refractory cooling spray water supply	X			
Ash hopper seal trough overflow/temperature		X		
Ash hopper transport nozzles/wear				X
Compressed-air system filters and traps	X			
Control valves/leakage		X		
Crusher roll(s)			X	
Crusher drive-chain and sprockets			X	
Crusher housing and wear plates			X	

Table 5-2 (cont.)
Operational Inspections: Bottom Ash and Mill Rejects Systems

Item	Frequency of Inspection			
	Daily	Weekly	Monthly	Quarterly
Crusher seals/leakage			X	
Dewatering bin element screens (visual inspection for plugging)		X		
Dewatering bin discharge gate/leakage			X	
Discharge line for mineral deposits/wear				X
Discharge line connections/leakage			X	
Discharge line/fittings for leakage			X	
Discharge line gates/valves			X	
Hydraulic accumulator		X		
Hydraulic cylinders/leakage			X	
Hydraulic cylinders/operation			X	
Hydraulic pump/oil level			X	
Hydraulic reservoir levels		X		
Jet pump combining tube			X	
Jet pump nozzle			X	
Mechanical pumps/drive			X	
Mechanical pumps/packing boxes		X		
Mill rejects hopper barometric seal/ash accumulation			X	
Mill rejects hopper barometric seal/water level	X			
Mill rejects hopper grid/material accumulation	X			
Mill rejects hopper mechanical seal/leakage			X	
Mill rejects isolating gate/valve			X	

5.2.1.2.1 Air Cylinders

Inspect air cylinders monthly for leakage. In a double-acting cylinder, leaking in the packing can usually be detected by a flow of air along the shaft. Sluggish air cylinder operation may be caused by internal leakage, an incorrectly adjusted flow-control device, low air pressure, or a malfunctioning solenoid valve. (A malfunctioning solenoid valve can usually be identified by a continuous flow of air from the vent port.) If an air cylinder is operating sluggishly, determine the cause and correct the condition.

5.2.1.2.2 Ash Hopper Discharge Gate Enclosure

Inspect the ash hopper discharge gate enclosure for leakage caused by wear or corrosion. If the enclosure is worn, the pressure of the diluting spray may be the cause. Excessive pressure increases the turbulence in the ash flow from the hopper. If the pressure exceeds that specified on the supplier's drawings, correct it.

If there is corrosion, check the pH of the hopper water. If it is below 5.5, contact the supplier for assistance in selecting a material for an enclosure that is more suitable for the existing conditions. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

Note: A significant leak from a discharge gate may make this inspection impossible until there is an outage.

5.2.1.2.3 Ash Hopper Discharge Gate

Inspect the gate of the ash hopper monthly for leaks. If leaks are present, the gate should be readjusted to minimize them. Refer to the supplier's drawings for instructions.

Note: In some cases, it is impossible to correct a leak while the unit is operating. In such cases, the leak must be corrected during an outage.

Other possible causes for a leaking gate include the following:

- Low air or oil pressure for the operating cylinder
- Internal leakage in the operating cylinder
- Leaking in the control valve

Determine the cause of any leak and correct the condition.

If the gate operation is slow or uneven, the piston rod of the operating cylinder may be bent or out of alignment. Check the piston rod: if alignment is not correct, refer to the supplier's drawings for instructions on aligning it. If it is bent, repair as needed.

5.2.1.2.4 Ash Hopper Overflow

The water temperature should not exceed the temperature specified on the supplier's drawings. If it does, the water flow to the internal cooling sprays, along with other continuous water input to the hopper, should be increased. If the temperature is below that specified on the supplier's drawings, the internal water flow can safely be reduced to the specified water flow for the hopper.

5.2.1.2.5 Ash Hopper Refractory Cooling Spray

To protect the refractory lining in the hopper, the water supply valve(s) for refractory cooling spray(s) should be checked daily to verify that they are open.

5.2.1.2.6 Ash Hopper Seal Trough

The overflow water temperature should not exceed the supplier's specification (usually 125–140°F [69–80°C]). Refer to the supplier's instructions for the proper temperature. If the temperature is above that specified, the water flow should be increased until the overflow temperature is at or below the specified temperature. If the temperature is below that specified, the water flow may be reduced as long as it is not below the supplier's specified minimum flow rate.

5.2.1.2.7 Ash Hopper Transport Nozzles

If the ash hopper system has a mechanical instead of a jet pump, a transport nozzle is required to move the ash to the mechanical pump inlet. The nozzle should be inspected quarterly for wear. If it is worn beyond the supplier's limit, it should be replaced. Refer to the supplier's instructions and drawings for the specific maximum wear allowed.

5.2.1.2.8 Compressed-Air System

Filters and traps in a compressed-air system should be inspected daily. Any material found should be removed to protect air-controlled equipment from plugging or malfunctioning.

5.2.1.2.9 Control Valves

Control valves should be inspected weekly for leakage to ensure proper operation of the equipment controlled by the valve. In most cases, the dewatering bin discharge gates are controlled manually. If the control valve leaks, the dewatering gates can creep, causing them to leak. A leaking control valve should be repaired or replaced.

5.2.1.2.10 Crusher Roll(s)

Inspect the crusher roll(s) monthly for wear and engagement. If the engagement of the roll(s) and the mating parts is inadequate, the particle size can increase; the larger particles can plug a jet pump or damage the impeller in a mechanical pump. Information on the required minimum engagement should be available from the crusher supplier. If the roll(s) or the mating parts are worn beyond specifications, they should be repaired or replaced.

On some crushers, it is possible to rebuild the roll(s) with a hard face applied by welding.

- If information regarding the welding rod to be used and the dimensions of the rebuilt face is not included in the instructions, contact the crusher supplier.

Note: A significant leak from a discharge gate may make it impossible to inspect or repair crusher rolls on-line. In this case, the inspection should be scheduled as an outage activity.

5.2.1.2.11 Crusher Chain Drive and Sprockets

Inspect the crusher chain drive and sprockets monthly for wear and proper adjustment. If the chain is incorrectly tensioned, it could fail prematurely. Refer to the supplier's drawings for the correct tension. Worn sprockets could allow the chain to disengage from the teeth and should be replaced.

5.2.1.2.12 Crusher Housing and Wear Plates

Inspect the crusher housing and wear plates monthly for wear. If the wear plates are worn through, they can expose the crusher housing to wear that causes leakage. Such wear plates should be replaced at the earliest opportunity. The housing can be worn by the diluting spray if the spray pressure is too high. High pressure increases turbulence in the flow of ash from the hopper, which also increases wear. A spray pressure above that specified on the supplier's drawings should be reset to conform to specifications.

Note: A significant leak from a discharge gate may make it impossible to perform this inspection until there is an outage.

5.2.1.2.13 Crusher Seals

Inspect the crusher seals weekly for leakage. If leakage is present, the crusher seals can allow ash-laden water from the crusher to enter the seals and damage the crusher shaft and the bearings (if they are face-mounted). If seals leak, they should be tightened only enough to stop the leakage. Seals that are overtightened can act as a brake on the crusher shaft, causing damage and even stalling. Overtightening also reduces the service life of the seals.

5.2.1.2.14 Dewatering Bin Dewatering Elements

Screens in the dewatering elements can be plugged either by ash that hardens on the screen surface or by a mineral accumulation. If either occurs, the dewatering rate is reduced.

- Perform a monthly visual inspection of the dewatering elements (screens) of the dewatering bin for plugging. Clean any plugged screens.

In both cases, back-flushing the screens whenever the tank is refilled may help to keep them clean. This requires that the dewatering bin be filled with water before it begins operation. A water supply line is connected to the dewatering element piping and used to fill the bin. The reverse flow may remove some of the ash and/or mineral deposits.

- If the dewatering bin has no back-flush connection, contact the system supplier for information on installing such an arrangement.

If the dewatering bins use tubular elements, a more effective (although inconvenient) back-flush method is to use a jet from a fire hose lowered into the elements from the top of the bin.

If the material that plugs the screens cannot be removed by a back-flush, it is necessary to remove the screens for cleaning. Most screens on dewatering elements can be replaced. If this is the case, a spare set of screens should be purchased. Plugged screens may then be replaced with clean screens, and the plugged screens may be cleaned on an available-time basis rather than as an emergency operation. After the screens are cleaned, they may be restocked for use.

Most screens are fabricated from stainless steel, which allows them to be cleaned manually or using an acid bath.

- When selecting an acid cleaner (such as muriatic acid), be sure that the solution is not strong enough to attack either the screens or the structures to which they are attached.

5.2.1.2.15 Dewatering Bin Discharge Gate

Inspect the discharge gate of the dewatering bin monthly for leakage. The discharge gate is not watertight but can be adjusted for minimal leakage.

- If the gate leaks excessively, readjust as necessary. Refer to the supplier's drawings for instructions.

The gate may also leak if the air pressure to the operating cylinder is low, the operating cylinder has internal leakage, or the control valve leaks.

- Determine the cause of the leakage and correct the condition.

If the gate operates slowly or unevenly, the piston rod of the operating cylinder may be bent or out of alignment.

- Check the piston rod. If alignment is incorrect, refer to the supplier's drawings for instructions on aligning the rod. If it is bent, repair as needed.

Any visible leakage at ground level could be the result of leak(s) in the drip pan beneath the discharge gate enclosure.

- Inspect the drip pan for wear. If it is worn through, repair should be made (ordinarily by welding a patch over the worn area).

5.2.1.2.16 Discharge Line, Bottom Ash

If the coal has a high calcium or sodium content, inspect the bottom ash discharge line quarterly for mineral deposits. Deposits can reduce the effective inside diameter of the pipe and thus the system capacity. If deposits are present, either an acid flush or a mechanical pipe-cleaning device is required.

Inspect the pipe for wear. If it is worn at the bottom, it is possible to increase its effective service life by periodically rotating the pipe in 90- to 120-degree (1.6- to 2.1-radian) increments.

5.2.1.2.17 Discharge Line Connections

Inspect discharge line connections monthly for leakage. If leakage is present, the connection should be tightened or remade (if the gasket is worn or damaged).

5.2.1.2.18 Discharge Line Fittings

Inspect the fittings of the discharge line monthly for leakage. If any fittings are beginning to leak, their replacement should be scheduled.

5.2.1.2.19 Discharge Line Gates or Valves

The operation of the gates and/or valves of a discharge line should be observed monthly.

Key Human Performance Point

The operation of the gates and/or valves of a discharge line should be observed monthly.

Sluggish operation can be caused by leakage in an actuating cylinder or by a faulty motor-driven operator. An actuating cylinder in an operator can be powered by compressed-air or by a closed hydraulic system.

- Inspect the cylinder and the solenoid valve that controls it for leakage. If either leaks, repair or replace the unit.

If the operator is motor-driven, inspect the drive for wear, corrosion, and electrical faults. If problems are found, repair or replace the operator. Refer to the instruction manual for repair instructions.

5.2.1.2.20 Hydraulic System Accumulator

Check the accumulator of the hydraulic system weekly for leakage and loss of pressure. If the accumulator loses pressure, it should be repaired or replaced.

- Refer to the supplier's instructions for the proper procedures for repairing or replacing the accumulator.

5.2.1.2.21 Hydraulic Cylinders

The hydraulic cylinders on the dewatering bin discharge gate can be operated by compressed air over hydraulic fluid or by hydraulic fluid only. The operation should be observed and the cylinders inspected monthly for leakage. Any internal leakage makes operation of the cylinder sluggish. Inspect the cylinder for leakage, and repair or replace any worn parts. Other possible causes of sluggish operation of a cylinder include low air pressure, low hydraulic pressure, or a leaking solenoid valve in the air system that supplies a hydraulic reservoir.

- Determine the cause of sluggish operation and correct the condition.

5.2.1.2.22 Hydraulic Pump

If the system has a hydraulic pump, the pump operation should be observed monthly. If the pump pressure is outside the limits shown on the supplier's drawings, the control switches should be recalibrated. The fluid level in the system should be checked and, if low, fluid should be added to restore the operating level. Refer to the supplier’s instructions for the correct fluid.

5.2.1.2.23 Hydraulic Reservoir

If a hydraulic reservoir is used in the operating mechanism of the discharge gates for either the ash hopper or dewatering bin, the fluid level should be checked weekly. If the level is low, fluid should be added to restore the operating level. An antifreeze type of fluid may be required, depending on the expected ambient temperature range.

5.2.1.2.24 Jet Pump

Inspect the combining tube of the jet pump monthly for wear.

Key Human Performance Point

Inspect the combining tube of the jet pump monthly for wear.

Refer to the supplier's drawings and instructions for the maximum recommended wear allowance for the throat diameter. If worn beyond this size, the tube should be replaced.

Note: If there is significant leakage from a discharge gate, it may not be possible to perform this inspection until there is an outage.

Inspect the nozzle of the jet pump monthly for wear. The typical allowance for wear is 1/16 inch (1.6 mm) on the diameter. The nozzle should be replaced if worn to the limit. Note that suspended solids in the water can reduce the service life of the nozzle.

- If the nozzles require frequent changes, contact the system supplier for information on nozzles with abrasion-resistant liners, such as ceramic or tungsten carbide.

Note: If there is significant leakage from a discharge gate, it may not be possible to perform this inspection until there is an outage.

5.2.1.2.25 Mechanical Pumps

Inspect the drive of each mechanical pump monthly for loose or damaged belts.

Key Human Performance Point

Inspect the drive of each mechanical pump monthly for loose or damaged belts.

Any belt that is loose but undamaged should be re-tensioned. If even one belt is damaged, the entire set of belts must be replaced.

- Refer to the supplier's instructions for the correct tensioning procedure.
- If the pump is direct connected, check the coupling alignment and lubrication.

The shaft packing boxes should be inspected weekly for leakage. Any packing box that leaks should be tightened according to the supplier's recommendations. The tightening must be performed carefully, as overtightening can have adverse effects on the shaft.

5.2.1.2.26 Mill Rejects Hopper Barometric Seal

Inspect the barometric seal of the mill rejects hopper monthly for ash accumulation at the bottom of the loop. A significant ash accumulation can interfere with correct seal operation.

- Remove any ash found.

If ash is often found, the seal should be flushed regularly.

- Refer to the supplier’s drawings and instructions for the proper flushing procedure.

Check the water level in the seal daily. If it is below the design level shown on the drawings, water should be added. Ensure that the water supply valve for the seal makeup water is open.

5.2.1.2.27 Mill Rejects Hopper Grid

Inspect the grid of the mill rejects hopper daily for any large pieces of material that may have accumulated, and remove any that are found. If the hopper has no grid to collect pieces large enough to plug the hopper outlet or the throat of the combining tube in the jet pump, such a grid could help system operation. Contact the system supplier for installation information.

5.2.1.2.28 Mill Rejects Hopper Mechanical Seal

Inspect the mechanical seal of a mill rejects hopper monthly. If the seal leaks, it may be defective. If the seal is a pinch-valve (sleeve-valve) type, the air pressure may require adjustment.

- Refer to the supplier's drawings for instructions on setting the air pressure.
- Inspect for worn or damaged parts. Repair or replace the seal if necessary.

5.2.1.2.29 Mill Rejects Isolating Gates/Valves

Inspect any isolating gates or valves used in the mill rejects system monthly for wear. If the gate or valve is a mechanical unit, repair or replace as required. Refer to the supplier's drawings and instructions for the proper repair procedures.

If a diaphragm valve is used, inspect it for wear and damage. If the diaphragm is worn or damaged, it should be replaced. Readjust the air pressure after any repairs. Refer to the supplier's drawing for instructions on replacing the diaphragm and adjusting the pressure.

5.2.1.3 Outage Inspections

5.2.1.3.1 Ash Hopper

Safety

- Never enter a bottom ash hopper until the boiler has cooled and all slag has been removed from the tubes. This will help to avoid injury caused by falling material.
- Never enter a bottom ash hopper unless the discharge gate is held in the open position by wooden supports or an acceptable equivalent. Be sure that all water-supply valves are locked in the closed position.
- Never enter a bottom ash hopper unless someone is stationed outside the enclosure, prepared to assist in case of an emergency.
- Never enter a bottom ash hopper unless there is a positive method to prevent firing of the boiler whenever a person is inside.

Table 5-3 summarizes the inspections that should be performed on bottom ash hoppers at each scheduled outage and notes their purposes. This table can be used to develop a checklist of the needed inspections, each of which is described briefly in the section referenced.

Table 5-3
Outage Inspections: Bottom Ash Hoppers

Item	Section	Inspection Purpose
Access doors and openings	5.2.1.3.1.1	Leakage, wear
Crusher	5.2.1.3.1.2	Body wear/corrosion
		Cam wear
		Chain and chain guard/wear
		Rotation detector/wear
		Seal wear
		Shaft wear/corrosion
Discharge gate	5.2.1.3.1.3	Adjustment
		Corrosion
		Face/wear
		Liners/wear
		Operating cylinder/leakage
		Seat/wear
Discharge gate enclosure	5.2.1.3.1.4	Access doors/leakage
		Corrosion
		Wear on the enclosure
		Wear on internal supports for the discharge gate
Ash hopper lining	5.2.1.3.1.5	Spalling
		Cracks
		Lost bricks
		Mortar damage
Nozzles, interior	5.2.1.3.1.6	Wear
		Alignment

Table 5-3 (cont.)
Outage Inspections: Bottom Ash Hoppers

Item	Section	Inspection Purpose
Nozzles, transport	5.2.1.3.1.7	Wear
Observation windows	5.2.1.3.1.8	Damage
		Leakage
Orifices, water supply	5.2.1.3.1.9	Wear
Overflows	5.2.1.3.1.10	Mineral accumulations
		Corrosion
Pressure- or vacuum-relief valves	5.2.1.3.1.11	Pressure-relief valve/wear and damage
		Vacuum-relief valve/wear and damage
Refractory water curtain	5.2.1.3.1.12	Trough/ash accumulations
		Trough and pipe/mineral accumulations
		Trough or pipe/distortion
Seal trough	5.2.1.3.1.13	Ash accumulations
		Nozzle wear/alignment
		Seal plate distortion
Water level probes	5.2.1.3.1.14	Calibration
		Corrosion

5.2.1.3.1.1 Access Doors and Openings

Inspect the access doors and openings for leakage, which may be due to gasket wear. If the gasket is worn or damaged, it should be replaced. If the door or opening is worn, the worn parts should be repaired or replaced as required. If pressurized poke holes are used, inspect the throat for wear or corrosion. If it is damaged, it should be replaced. The nozzles and manifold should also be inspected, and any part that shows wear should be replaced.

5.2.1.3.1.2 Crusher

Inspect the crusher body for wear and corrosion. If it is worn, it should be repaired (if possible). If the crusher body cannot be repaired, a new one should be installed. Inspect the wear plates and liners for wear and corrosion; replace any that show excessive wear. Any parts that mesh with the crusher rolls should be replaced when worn beyond the design limits.

- Contact the crusher supplier for information on the maximum allowable wear if this information is not included on the crusher drawings.

If corrosion is present and the hopper water has a pH below 5.5, contact the crusher supplier regarding corrosion-resistant crusher parts suitable for the conditions experienced. Because the roll(s) and liners are typically made of alloys that are both abrasion- and corrosion-resistant, the body is generally the only part affected by corrosion. Stainless steel bodies (usually type 316 stainless) are available from all crusher manufacturers.

Inspect the rolls for wear. If information about the maximum allowable wear does not appear on the drawings of the crusher or rolls, contact the crusher supplier. Some rolls can be rebuilt by welding using a hard-surface welding rod.

- Contact the crusher supplier regarding 1) resurfacing the rolls, 2) the recommended welding rod to be used, and 3) the finished dimensions of the roll after resurfacing.

If the cams are worn beyond design limits, they should be replaced.

Roll wear can be accelerated if ash is not accepted by the conveyor pump because the ash concentration in the slurry from the hopper is too high. If ash remains in the crusher, the rolls can churn in stationary ash, which increases wear.

- Ensure that the ash is correctly slurried in the hopper and that the diluting spray is used. Refer to the system instructions for the correct procedure for slurrying ash before the discharge gate is opened, using internal hopper nozzles for slurrying.
- Inspect the drive chain for wear and tension. If the chain is worn, replace either the entire chain or only the defective links. The tension of the chain should meet the requirements stated on the supplier's drawings.
- If the chain is not correctly tensioned, re-tension it to meet the supplier's requirements.
- Inspect the chain guard for wear. Repair or replace any support that is worn or corroded.

The rotation-detector part(s) on the crusher shaft should be inspected for wear and any worn part replaced. The sensing unit should also be inspected for wear and any worn part replaced. If any part is replaced, the rotation sensor should be recalibrated.

Inspect the shaft seals. If the packing or bearings in the seal are worn, the worn part(s) should be replaced. The seal should be lubricated according to the instructions on the supplier's drawings. The seal must not be overtightened or overlubricated after repair. Either of these conditions can act as a brake on the shaft, overheating or possibly stalling the crusher.

Inspect the shaft and the cam support structure for wear and corrosion. Any worn part in the cam support structure should be replaced. If the shaft is worn, it should be replaced.

- If the wear is located near the seals, check the supplier's drawings for instructions on refinishing the journal area. If there are no instructions, contact the supplier for a kit or instructions on refinishing the shaft.

5.2.1.3.1.3 Discharge Gate

During the outage and after any repairs, the discharge gate should be adjusted for proper closing position. Refer to the supplier's drawings for the correct procedure for adjusting the gate to allow minimum leakage. The alignment of the piston rod on the operating cylinder should also be checked. If the piston rod is not properly aligned, it can bind and cause the gate to move slowly.

The gate guides, supports, and other wetted fittings and fasteners should be inspected for wear and corrosion. If any part is worn, it should be repaired or replaced. If corrosion is present and the hopper water has a pH below 5.5, contact the hopper supplier regarding corrosion-resistant parts suitable for the conditions experienced. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

Inspect the gate face for wear that allows leakage. If the nozzles used for slurrying operate for too long a time before the discharge gate is opened, the turbulence can increase wear on the face of the gate. Refer to the system instructions for the correct slurrying procedure.

If the gate has a replaceable face that is worn, a new face should be installed. Some suppliers offer replaceable gate faces fabricated from either rubber or stainless steel. A rubber gate provides better sealing when the gate is closed, while a stainless steel gate face provides more resistance to abrasion and corrosion. Contact the hopper supplier for information on gate faces fabricated from different materials. If the gate is worn and does not have a replaceable seat, the entire gate should be replaced.

Many gates have liners within the hopper that protect the hopper shell and refractory from abrasion by ash when it is flowing out of the hopper. During any outage, such liners should be inspected. Any liner that is worn should be replaced.

- If the hopper discharge gate has no wear liners, contact the hopper supplier to determine the availability of such liners.

The operating cylinder should be inspected for leakage. If there are any indications of leakage, the cylinder should be repaired. Some water conditions cause a mineral accumulation to form on the walls of the cylinder; others cause corrosion. Inspect the internals of the cylinder for these conditions. If either condition occurs, contact the ash hopper supplier for information on a hydraulic fluid that will not damage the seals and piston. This fluid should be used instead of water in the hydraulic reservoir that operates the discharge gate.

The seating surface for the discharge gate should be inspected for wear and replaced (if possible). If the discharge gate of the hopper does not have a replaceable seat, contact the supplier regarding the availability of one.

5.2.1.3.1.4 Discharge Gate Enclosure

All access doors and openings in the enclosure should be inspected for leakage, which usually causes rusty stains on the enclosure. If leakage has occurred, the gaskets should be inspected for wear or damage. Any that are worn or defective should be replaced.

The gate enclosure should be inspected for wear and corrosion. If there has been significant wear on the enclosure, the pressure of the diluting spray should be checked. High pressure in the spray increases turbulence in the ash flow from the hopper and thus increases wear.

- If the spray pressure exceeds that specified on the drawings, reset the pressure to the correct value.

If evidence of corrosion is present and the pH of the hopper water is below 5.5, the hopper supplier should be contacted for corrosion-resistant material for rebuilding or replacing the enclosure to suit existing conditions. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

The internal supports of the discharge gate should be inspected for wear and corrosion. If worn, they should be replaced. See the previous paragraph if there are indications of corrosion.

Note: The supports for the gate cannot be replaced directly by dimensionally identical parts of corrosion-resistant material. Because corrosion-resistant materials are not always as strong as carbon steel, supports with a heavier cross-section should be used for channels or angles. Analysis is required to determine the correct size to use for replacements.

5.2.1.3.1.5 Ash Hopper Lining

The lining should be inspected for spalling, especially near the normal water level. If spalling is found, the damaged area should be repaired. One cause of spalling is loss of the cooling spray for the refractory lining. If the lining is first exposed to the radiant heat from the furnace and then covered with cold water, the abrupt temperature change causes a quenching shock to the lining.

The water-curtain spray pipe or trough should be inspected for plugging and distortion. An ash or sediment accumulation in the water-curtain pipe or trough indicates that the flushing is inadequate.

- Refer to the supplier's drawings for the recommended minimum flushing time and pressure.

If the flushing is manually controlled, it may not be performed as frequently as recommended. Most suppliers can provide an automatic flushing system.

- If the flushing is manually controlled, contact the system manufacturer for information on automatic flushing systems.

Radiant heat from the furnace causes a water-curtain spray pipe or trough to be distorted, indicating that the water flow has been interrupted.

- Inspect the water supply valve daily to ensure that it is open.

If the water curtain comes from either the trough or the overflow weir, accumulation of ash or sediment in the trough may have caused the interruption. See the previous paragraphs for information on flushing.

Any cracks in the lining (often caused by slag falling into the hopper) should be repaired. A large piece of ash falling into the hopper causes an impact shock as the ash hits the water or the lining and a thermal shock as the hot material falls into the hopper water.

- Contact the boiler or sootblower supplier for assistance in preventing accumulation of ash on the tubes, because this ash becomes the slag that eventually falls into the hopper.

In a hopper that uses a brick lining on its sloped walls, any missing bricks should be replaced. The loss of bricks can be the result of poor installation, impact (described in the previous paragraph), or misaligned flushing nozzles. Replacement bricks must be correctly installed and the mortar bed correctly applied.

- Refer to the supplier's instructions for installation of brickwork.

5.2.1.3.1.6 Nozzles, Interior

The nozzles within an ash hopper should be inspected for wear. A nozzle worn more than 1/16 inch on the diameter should be changed. The nozzle holder or coupling should also be inspected for wear and any worn items replaced. Suspended solids in the water supply can reduce the life of the nozzles.

- Contact the system supplier for information on nozzles made of abrasion-resistant material, which can improve their service life.

Nozzle alignment should also be checked using a short length of pipe or drill rod inserted in the nozzle. Incorrectly aligned nozzles can cause erosion of the hopper lining.

- Refer to the supplier's drawings for the correct alignment of the nozzles used. The nozzle holders must be the correct ones for the required nozzle angle.

5.2.1.3.1.7 Nozzles, Transport

Some systems use nozzles to move ash from the crusher outlet to the inlet of the mechanical slurry pump. Such nozzles should be inspected for wear and, if worn more than 1/16 inch (1.6 mm) on the diameter, should be replaced.

5.2.1.3.1.8 Observation Windows

Observation windows should be inspected for damage and leaks, and any damaged window glass should be replaced. Damage to such windows may be caused by impact and thermal shock from slag falls. Another possible cause is quenching shock, if the windows are exposed to the radiant heat from the furnace with no protection by a cooling spray. If the hopper has cooling sprays for its windows, they should be used.

Leakage from observation windows can usually be observed as stains on the hopper and is often the result of worn or damaged window gaskets. Worn or damaged gaskets should be replaced.

5.2.1.3.1.9 Orifices, Water Supply

The orifices in the water supply piping should be inspected and any orifice worn more than 1/16 inch (1.6 mm) on the diameter replaced. The correct sizes of the orifices can be obtained from either the supplier's or the consulting engineer's drawings. If the sizes are not shown on the drawings, the plant engineers should be able to calculate the required sizes from the drawings by using the flow and pressure requirements for the various items of equipment. Worn orifices affect the water flow and pressure from the nozzles and other components that have orifice control. For example, worn orifices can cause low water pressure to a jet pump, resulting in system shutdown.

5.2.1.3.1.10 Overflows

If the ash has high calcium content, a mineral deposit may form, plugging the overflow inlets to the extent that overflows cannot handle the water from the hopper. Then the water may overflow through the seal trough. Therefore, any mineral deposits should be removed. If the overflow inlets plug between outages, contact the hopper supplier for information on enlarging them.

Inspect the overflow boxes for corrosion. If they are corroded and the pH of the hopper water is below 5.5, contact the hopper supplier for information on obtaining overflow boxes fabricated from corrosion-resistant material suitable for the conditions experienced. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

5.2.1.3.1.11 Pressure- or Vacuum-Relief Valves

The pressure-relief valve on each discharge door enclosure should be inspected for wear and damage, especially if the valve vents into the hopper. Leakage from a worn or damaged pressure-relief valve can allow water to drip into the enclosure, making any work performed in the enclosure difficult—depending on the amount of leakage.

- Replace a leaking or damaged pressure-relief valve.

Systems that use a rubber flapper pressure-relief valve require cooling water to protect the flapper from heat and a spray nozzle to flush ash particles from the seat.

The vacuum-relief valve should be inspected for wear and corrosion. A worn or corroded valve may be unable to relieve vacuum, which can cause damage and possibly lead to injury. The enclosure will be under the vacuum generated by the conveyor pump until the discharge gate is opened. Without vacuum relief, the enclosure could be fully or partially collapsed by the vacuum.

- Replace a worn or corroded vacuum-relief valve.

5.2.1.3.1.12 Refractory Water Curtain

If a water curtain for the refractory is provided through the overflow trough, the trough should be inspected for accumulations of ash or sediment.

- Remove any ash or sediment accumulation from the overflow trough.

A major accumulation indicates inadequate flushing. Refer to the system instructions for the flushing requirements. If the flushing is manually controlled, it may not be performed as frequently as recommended. Most suppliers can provide an automatic flushing system.

- Contact the system manufacturer for information on automatic flushing systems if the operation is manually controlled.

If the system uses recirculated water and the ash has a high calcium content, the water curtain trough or pipe can have a mineral accumulation that interferes with the water flow. This can damage both the water curtain equipment and the hopper lining.

- If there is a mineral accumulation, contact the hopper supplier for assistance in minimizing the problem.

A distorted water curtain pipe or trough (caused by radiant heat from the furnace) indicates that the water flow has been interrupted. If the water curtain uses a trough, the water flow can be interrupted by an ash or sediment deposit in the trough.

- Inspect the water supply valve daily to ensure that it is open.

5.2.1.3.1.13 Seal Trough

Although access to the seal trough may be difficult (for example, because the hopper does not have access openings in the seal trough), it should be inspected for ash accumulations. In such a case, installing an access opening in the seal trough at each of the four corners allows inspection with minimal difficulty. Plant personnel can install the access openings during an outage by making a cutout on each corner and fabricating a cover plate. The cover plates should bolt to the seal trough, using gaskets to make watertight seals.

A major ash accumulation can jam the boiler seal plate, preventing relief of pressure within the hopper by the water seal—a condition that can damage the seal plate. Any ash accumulation should be removed, although a major accumulation of ash indicates that flushing is inadequate for removal. Refer to the system instructions for flushing requirements. If flushing is manually controlled, it may not be performed as frequently as recommended. Most suppliers can provide an automatic flushing system.

- Contact the system manufacturer for information on an automatic flushing system if the operation is manually controlled.

Inspect the flushing nozzles for wear and alignment. Replace nozzles worn more than 1/16 inch (1.6 mm) on the diameter. If a nozzle is replaced, it should be properly aligned as shown on the supplier's drawings.

5.2.1.3.1.14 Water Level Probes

An ash hopper typically has probes that annunciate high water level and emergency high water level. In some cases, the normal high level probe can stop the refilling of the hopper. The probes should be checked for calibration and any incorrectly calibrated probe recalibrated.

Inspect the probes for corrosion or mineral accumulations that can cause the probe to produce spurious annunciations.

- If the probe is corroded and the pH of the hopper water is below 5.5, contact the system supplier regarding a more corrosion-resistant probe.
- If a probe has a mineral accumulation and the hopper water pH is above 8.5, contact the system supplier for information on the availability of a probe that resists calcium accumulations.

5.2.1.3.2 Bottom Ash Conveyor

When performing any work or inspections on the conveyor line or related equipment, observe all plant safety regulations and review the supplier's instruction manuals for safety information on specific items or equipment.

Table 5-4 summarizes the inspections that should be performed on a bottom ash conveyor system at each scheduled outage and notes their purposes. This table can be used to develop a checklist for the needed inspections, each of which is described briefly in the section referenced.

Table 5-4
Outage Inspections: Bottom Ash Conveyor

Item	Section	Inspection Purpose
Anchors and guides	5.2.1.3.2.1	Tightness
Expansion joints	5.2.1.3.2.2	Anchoring Corrosion Wear
Jet pump	5.2.1.3.2.3	Body/wear Combining tube/wear Nozzle/wear Nozzle holder/wear
Line valves	5.2.1.3.2.4	Alignment/disc or slide Body/wear Disc/wear Operating cylinder/leakage, wear Slide wear
Mechanical pump	5.2.1.3.2.5	Body/corrosion and wear Drive/belts Impeller/corrosion and wear Packing
Pipe	5.2.1.3.2.6	Mineral accumulations Wear

5.2.1.3.2.1 Anchors and Guides

Inspect the anchors and guides for tightness and tighten any that are loose. Loose anchors can allow movement at the elbows and the expansion joints, which can cause pipe connections to fail.

- If there is any question about the adequacy of the anchors, refer to the supplier’s drawings for the forces that must be restrained. Contact the system supplier if the information is not included on the drawings.

If the routing of the conveyor or the conveyor length has changed and the conveyor pump output has been adjusted to compensate for the change, new or additional anchors may be required to restrain the pipe.

- Contact the system supplier for information on any resulting changes of the forces that act on the conveyor.

5.2.1.3.2.2 Expansion Joints

The anchoring at the outlet of the expansion joints should be inspected for tightness. Unless the expansion joint is anchored, it cannot absorb expansion and contraction in the conveyor line.

Inspect the sliding surfaces of the expansion joints for corrosion. If the surfaces are corroded, the expansion joints may be unable to move correctly to accommodate movement. If possible, clean the sliding surfaces of the expansion joints. If they cannot be cleaned, install a new part, including the sliding surface. Some expansion joints have a chromed sliding surface: if this is damaged, it may be possible to replace it.

Any worn parts of the expansion joints or gaskets should be replaced. Some bell-and-spigot expansion joints use packing instead of gaskets. If the packing is worn, it should be replaced.

5.2.1.3.2.3 Jet Pump

Jet pumps should be inspected for wear in the body, combining tube, nozzle, and nozzle holder. Replace any worn parts. The manufacturer’s drawings and instructions provide the maximum allowable wear on the diameter of the combining tube throat.

- If the combining tube requires frequent replacement, contact the system supplier for information on a combining tube fabricated from a more abrasion-resistant alloy.

The nozzle should be replaced if it is worn more than 1/16 inch (1.6 mm) on the diameter.

- If there are suspended solids in the water supply that reduce the service life of the nozzle, contact the system supplier for information on nozzles lined with an abrasion-resistant material to reduce the frequency of nozzle changes.

5.2.1.3.2.4 Line Valves

Inspect each line valve gate in the closed position. The supplier’s drawings show the alignment of the hole in the slide to the opening in the body for a totally enclosed rotary slide valve. If a butterfly valve is used, the closed position of the disc is shown. If any repairs are made, adjust the valve for the correct closed position.

Inspect each valve in the open position for wear on the slide, disc, and body. If any part is worn, it should be replaced. Wear on the seat of a butterfly valve in the 2, 4, 8, and 11 o’clock positions indicates that it may not be closing completely. The valve must be correctly adjusted in the closed position.

A badly worn body of a totally enclosed rotary slide valve and an eccentric hole worn in the slide indicate that the valve was not correctly adjusted.

- Refer to the supplier's drawings for the correct valve adjustment.

Inspect the operating cylinder for leakage. If there is any leakage, repair or replace the operating cylinder as required. The stroke of the cylinder should be readjusted to ensure that the valve closes and opens correctly after any significant change, such as when the operating cylinder is repaired or replaced, any parts on the valves are replaced, or a valve is reassembled following an inspection that involves disassembly.

5.2.1.3.2.5 Mechanical Pump

Mechanical pump(s) should be inspected for wear and corrosion, and the internal clearances between the impeller and the body should be verified. If the clearances are greater than those specified in the manufacturer's instructions, the worn part(s) should be replaced. Shafts and seals should also be inspected for wear or damage, and any damaged or worn parts should be replaced.

- Refer to the manufacturer's drawings and instructions for detailed information on inspection and repair procedures.

If signs of corrosion are present, contact the pump manufacturer regarding parts fabricated from corrosion-resistant materials that are better suited to existing conditions.

Inspect the drive for worn bearings, worn or damaged belts, and worn sheaves on the pump and motor; replace any worn or damaged parts. If even one belt is worn or damaged, the entire set of belts must be replaced.

- Refer to the manufacturer's drawings and instructions for procedures for installing and tensioning the belts.

Inspect the packing boxes for wear and leakage. If there is any wear, the packing should be replaced. Refer to the pump instructions for the proper replacement procedure.

5.2.1.3.2.6 Pipe

Inspect the pipeline by removing selected lengths. If the bottom quadrant is worn, the effective service life of the pipe can be increased by rotating the pipe in 90- to 120-degree (1.6- to 2.1-radian) increments, depending on the wear. If the pipe is badly worn, it should be replaced. Highly abrasive ash increases the rate at which the pipe wears. Pipe lined with an abrasion-resistant liner should increase the effective service life of the conveyor line.

- Contact the original system supplier or an alternative pipe supplier for information on suitable pipe.

If the ash (coal) has a high calcium content, the line may have a mineral accumulation on the walls. Any mineral accumulation must be removed using a chemical flushing operation or a mechanical pipe-cleaning device.

5.2.1.3.3 Dewatering Bin

Safety

- Do not enter a dewatering bin to perform any work or inspections unless 1) the water supply valves to the bin have been locked closed and 2) the diverting gates are locked closed so that no water or ash can enter the bin.
- Do not enter a dewatering bin alone. Another person must be stationed at the top of the bin and be prepared at all times to provide assistance in case of emergency.
- Follow all plant safety regulations when working in or around a dewatering bin. The supplier’s instruction manuals must be reviewed for safety information on specific items or equipment.

Table 5-5 summarizes the inspections that should be performed on a dewatering bin at each scheduled outage and notes their purposes. This table can be used to prepare a checklist for the needed inspections, each of which is described briefly in the section referenced.

Table 5-5
Outage Inspections: Dewatering Bin

Item	Section	Inspection Purpose
Anti-turbulence inlet section	5.2.1.3.3.1	Impact plate/corrosion, wear Skirt/corrosion, wear
Dewatering elements and screens	5.2.1.3.3.2	Ash accumulation Mineral accumulation Wear
Discharge gate	5.2.1.3.3.3	Adjustment Corrosion Face/wear Liners/wear Operating cylinder/leakage Seat/wear
Discharge gate enclosure	5.2.1.3.3.4	Corrosion Wear on the enclosure Wear on the internal supports for the discharge gate
Drip pan	5.2.1.3.3.5	Wear Bearing wear Operating cylinder/leakage, wear
Orifices and dewatering piping	5.2.1.3.3.6	Wear
Overflow weir	5.2.1.3.3.7	Ash accumulations Wear
Shell (tank)	5.2.1.3.3.8	Corrosion Wear

5.2.1.3.3.1 Anti-Turbulence Inlet Section

If a bin has an anti-turbulence inlet arrangement, the impact plate should be inspected for corrosion and wear. If the plate is corroded and the water pH is below 5.5, contact the dewatering bin supplier regarding an impact plate fabricated from a more corrosion-resistant material.

Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice. If the impact plate has major wear, it should be replaced. If repairs to the impact plate are attempted, determine whether the plate is fabricated from a special alloy. If it is, ordinary welding procedures may damage the temper of the plate.

- Contact the welding material supplier for the type of rod and welding procedures to be used for repairs.

The skirt and supports should also be inspected for corrosion and wear. If any part is worn or corroded, it should be repaired or replaced. See the preceding paragraph for information on weld repairs.

If a dewatering bin has no anti-turbulence inlet arrangement, investigate the value of one for minimizing carry-over from the dewatering bin.

5.2.1.3.3.2 Dewatering Elements and Screens

Screens in the dewatering elements can be plugged by mineral accumulations or by ash that hardens on the surfaces. Because a plugged screen reduces the dewatering rate, the screens must be cleaned.

- Visually inspect the dewatering elements and screens. Clean any that are plugged.

Back-flushing of the screens whenever the tank is refilled may be helpful. This involves filling the dewatering bin with water before operating it. A water supply line connected to the dewatering element piping is used to fill the bin. Reverse flow may remove some of the ash and/or mineral deposits.

- If the dewatering bin has no back-flush connection, contact the system supplier for information on installing such an arrangement.

If the dewatering bins use tubular elements, an effective (although inconvenient) back-flush method is to lower a fire hose into the elements from the top of the bin.

If the material plugging the screens cannot be removed by a back-flush, the screens must be removed for cleaning. Most screens on dewatering elements can be replaced. If this is the case, a spare set of screens should be purchased. This allows plugged screens to be replaced rapidly by clean screens. The plugged screens can then be cleaned on an available-time basis rather than as an emergency operation. After the screens are cleaned, they can be stocked for use whenever the set in service plugs and requires replacement.

- Contact the bin supplier regarding replacement screens.

Most screens are fabricated from stainless steel, which allows them to be cleaned manually or using an acid bath. In selecting an acid cleaner (such as muriatic acid), choose a solution that will not attack the screen material.

5.2.1.3.3.3 Discharge Gate

During the outage and after any repairs, the discharge gate should be adjusted to ensure the proper closing position.

- Refer to the supplier's drawings for the proper procedure to adjust the gate for minimum leakage.

The alignment of the operating cylinder piston rod should also be checked. An incorrectly aligned piston rod can bind and cause the gate to move slowly.

The gate guides, supports, and other wetted fittings and fasteners should be inspected for wear and indications of corrosion. Repair or replace any worn part.

- If corrosion is present and the pH of the system water is below 5.5, contact the hopper supplier regarding corrosion-resistant parts suitable for the conditions experienced. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

Inspect the gate face for wear that allows leakage. If the gate has a replaceable face, a new face should be installed. Some suppliers offer replaceable gate faces fabricated from rubber or stainless steel. A rubber gate face provides better sealing when the gate is closed; a stainless steel gate face provides more resistance to abrasion.

- Contact the hopper supplier regarding the availability of gate faces fabricated from different materials.

If the gate is worn and does not have a replaceable seat, the entire gate should be replaced.

Inspect the operating cylinder for leaks. If indications of leakage are present, the cylinder should be repaired. Water can contain minerals that accumulate on the walls of the cylinder or cause corrosion.

- Inspect the internals of the cylinders for accumulations and corrosion. If either condition is found, contact the ash hopper supplier for information on the use of a hydraulic fluid that will not damage the seals and piston. This fluid is to be used instead of water in the hydraulic reservoir if the system uses a compressed-air actuated reservoir to operate the discharge gate.

The seating surface for the discharge gate should be inspected for wear. Some suppliers use a replaceable seat for the discharge gate. If a replaceable seating surface is worn, it should be replaced. If the discharge gate does not have a replaceable seat, contact the supplier for information on the availability of this item.

5.2.1.3.3.4 Discharge Gate Enclosure

Access doors and openings in the enclosure should be inspected for leakage (any leakage normally causes stains on the enclosure). If there has been leakage, the gaskets should be inspected for wear or damage. Any gasket that is worn or defective should be replaced.

Inspect the enclosure for wear and corrosion. If corrosion is present and the system water pH is below 5.5, contact the hopper supplier for assistance in selecting corrosion-resistant materials for rebuilding or replacing the enclosure to suit the existing conditions. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

The internal supports for the discharge gate should be inspected for wear and corrosion. If worn, they should be replaced. See the previous paragraph if indications of corrosion are present.

Note: The supports for the gate cannot be replaced directly by dimensionally identical parts of corrosion-resistant material. Corrosion-resistant materials are sometimes not as strong as carbon steel, and a heavier section should be used for channels or angles used as supports. This requires analysis to determine the correct size to use for replacements.

5.2.1.3.3.5 Drip Pan

The drip pan under the discharge gate enclosure should be inspected for wear. If it is worn, there is probably leakage from the discharge gate area. A worn drip pan should be repaired, which is ordinarily done by welding a patch over the worn area.

Inspect the bearings on the support shaft for wear or damage. Worn or damaged bearings should be repaired or replaced as required.

5.2.1.3.3.6 Orifices, Dewatering Piping

Inspect the orifices in the dewatering piping for wear. If the orifices are worn more than 1/16 inch (1.6 mm) on the diameter, they should be replaced. The correct diameter of the orifices is given on the drawings of the dewatering bin and the related instructions. Worn orifices increase the rate at which the bin dewaters, causing problems with both dewatering and emptying.

5.2.1.3.3.7 Overflow Weir

Inspect the overflow weir for ash accumulations in the bottom of the trough and remove any accumulations. A major ash accumulation indicates a high rate of ash carry-over. This can result from turbulence in the dewatering bin or a change in the water flow characteristics of the system. If there is no anti-turbulence outlet, installing one could help to reduce carry-over.

If the weir surface is worn, the water flow can short circuit across the surface of the bin and cause additional carry-over. If the weir is significantly worn, it should be repaired or replaced.

5.2.1.3.3.8 Shell (Tank)

The interior and exterior of the shell of the bin should be inspected for corrosion and wear. If the system water pH is below 5.5, corrosion could result. Contact the bin supplier for recommendations on minimizing corrosive damage.

If the bin is worn, repair any worn area. Contact the bin supplier for recommendations on repairs.

5.2.1.3.4 Mill Rejects (Pyrites)

When performing any work or inspections on the mill rejects system, observe all plant safety regulations and review the supplier's instruction manuals for safety information on specific items of equipment.

Table 5-6 summarizes the inspections that should be performed on a mill rejects system at each scheduled outage and notes their purposes. This table can be used to develop a checklist of the needed inspections, each of which is described briefly in the section referenced.

Table 5-6
Outage Inspections: Mill Rejects System

Item	Section	Inspection Purpose
Hopper	5.2.1.3.4.1	Access doors/leakage and wear Barometric seal/ash accumulations Barometric seal/wear Body/corrosion and wear Grid/wear Inlet gate/wear Inlet gate/operating cylinder Level-probe/calibration, wear Mechanical seal/calibration Mechanical seal/leakage, wear
Isolating gates or valves	5.2.1.3.4.2	Wear
Jet pump	5.2.1.3.4.3	Body/wear Combining tube/wear Nozzle/wear Nozzle holder/wear, corrosion
Mechanical pump	5.2.1.3.4.4	Body/corrosion and wear Drive/belts Impeller/corrosion and wear
Storage and transfer tanks	5.2.1.3.4.5	Body/corrosion and wear Outlet gate/wear

5.2.1.3.4.1 Hopper

Inspect the access doors of each hopper for leakage and wear; replace any worn part. If indications of leakage are present (usually in the form of stains on the hopper body), inspect the gaskets for wear or damage. If they are defective, they should be replaced.

Inspect the barometric seal for ash accumulation at the bottom of the loop. A significant ash accumulation can interfere with the correct operation of the seal. Remove any ash found. A major ash accumulation, however, indicates a need for the seal to be flushed regularly. Refer to the supplier's drawings and instructions for the correct flushing procedure.

Inspect the body of the hopper for corrosion and wear. If corrosion is present, contact the hopper supplier for information regarding a hopper fabricated from corrosion-resistant material to suit the existing conditions. Inspect the interior of the body, especially the outlet cone, for wear.

Inspect the grid that is used to collect large pieces of material discharged by the mill; if the grid is corroded or worn, it should be repaired or replaced. If the hopper does not have a grid, it can pass particles large enough to plug the hopper outlet or the throat of the combining tube of the jet pump. The addition of such a grid, therefore, could benefit system operation. Contact the system supplier for information on the installation of such a grid.

Inspect the hopper inlet gate for wear. A worn gate can allow water to enter the mill when the hopper fills with water as the mill rejects conveyor system shuts down. Any worn parts should be replaced. Refer to the instruction manual for drawings and instructions on replacing the gate. Inspect the operating cylinder for wear and leakage. A cylinder with worn parts should be repaired or replaced as required.

If the hopper uses a level probe to annunciate a full-hopper condition, check the probe for calibration, inspect it for wear, and (if necessary) recalibrate it. The procedure for calibrating the probe can be found in the manufacturer's instructions. The seal and the part of the probe that extends into the hopper should be inspected for wear or damage. Any worn or damaged part should be replaced.

Inspect the mechanical hopper seal for wear and leakage and for worn or damaged parts. If leakage is present, the seal may be defective and should be repaired or replaced as necessary. If the seal is a pinch-valve (sleeve-valve) type, the air pressure may require adjustment. Refer to the supplier's drawings for instructions on setting the air pressure.

5.2.1.3.4.2 Isolating Gates or Valves

Inspect any gates or valves for wear on their internals and on their operating mechanisms. Repair or replace the gate or valve as needed. Refer to the drawings in the instruction manual for repair instructions.

If the valve has a rubber diaphragm, inspect it for wear and damage. Replace a worn diaphragm, making sure to readjust the air pressure after replacement. Refer to the valve drawings for instructions on replacing the diaphragm.

5.2.1.3.4.3 Jet Pump

Jet pumps should be inspected for wear on the body, combining tube, nozzle, and nozzle holder. Replace any parts that are worn. The drawings and instructions should give the maximum allowable wear on the diameter of the combining tube throat. The nozzle should be replaced if it is worn more than1/16 inch (1.6 mm) on the diameter. If there are suspended solids in the water supply that reduce the service life of the nozzle, contact the system supplier regarding the availability of nozzles lined with an abrasion-resistant material (such as ceramic or tungsten carbide) to decrease the frequency of nozzle changes.

5.2.1.3.4.4 Mechanical Pump

Mechanical pumps should be inspected for wear and corrosion. The internal clearances between the impeller and the body should also be checked. If the clearances are greater than those specified in the manufacturer's instructions, replace the worn part(s). Inspect shafts and seals for wear or damage, and replace any damaged or worn parts. Refer to the manufacturer's drawings and instructions for detailed information on inspection and repair procedures.

Inspect the drive for worn bearings, worn or damaged belts, and worn sheaves on the pump and motor. Replace any worn or damaged parts. If even one belt is worn or damaged, the complete set must be replaced. Refer to the manufacturer' s manuals for instructions on installing, tensioning, and re-tensioning belts.

Inspect the packing boxes for indications of leakage and wear. If there is leakage or wear, replace the packing. Refer to the supplier's manual for instructions.

5.2.1.3.4.5 Storage and Transfer Tanks

If a storage tank or a transfer tank is used in the system, inspect the interior of the tank body for wear or corrosion. If corrosion is present, consult the tank supplier regarding a more corrosion-resistant material for the tank. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

The mill-reject material can be very abrasive. If the body of the tank has significant wear, the shell should be repaired. In most cases, patching the tank is sufficient. Before making repairs, however, check the supplier's drawings or contact the supplier for information concerning the material of the tank. If the tank was fabricated from abrasion-resistant material, welding it could cause damage. Consult the welding material supplier for assistance in choosing the correct welding rod and technique for the tank material.

If the tank has an outlet gate, it should be inspected for wear and any worn parts repaired or replaced. Inspect the operating cylinder for leakage. If leakage is present, the cylinder should be repaired or replaced as required.

5.2.2 Recirculating Water Systems

Safety

When performing any work or inspections on the recirculating system, observe all plant safety regulations. Review the supplier's instruction manuals for safety information on items of equipment.

System Design

There are many variations in the design of recirculating systems and many possible combinations of different types of pumps for various functions. Some systems use settling and surge tanks, others use settling and surge ponds, and still others use a combination of settling tanks and surge ponds. Therefore, the maintenance information presented in this section is limited to general, common features and does not cover all possible types of systems.

5.2.2.1 Lubrication

Table 5-7 summarizes the lubrication requirements for recirculating water systems. The table can be used to develop checklists for lubrication of each component at regular intervals. Additional information is provided in Sections 5.2.2.1.1 through 5.2.2.1.4.

Table 5-7
Lubrication Items: Recirculating Water Systems

	Frequency of Lubrication			
Item	**Daily**	**Weekly**	**Monthly**	**Quarterly**
Compressed-air lubricators	X			
Hydraulic pump			X	
Pump/drive		X		X
Pump/drive, change lubricant				X
Pump/packing box		X		
Valves			X	

5.2.2.1.1 Compressed-Air Lubricators

The lubricant level should be checked daily. If it is low, the lubricator should be refilled.

5.2.2.1.2 Hydraulic Pumps

The pump drives should be lubricated at least monthly or as specified on the drawings or in the supplier's instructions.

The lubricants of the pump and the drive should be changed at least quarterly or according to the schedule provided in the instructions. Use a lubricant specified for the ambient conditions for the pump and drive.

5.2.2.1.3 Pumps

The pump drives should be lubricated monthly or as specified on the drawings or in the supplier's instructions.

The lubricants of the pump and the drive should be changed at least quarterly or according to the schedule provided in the instructions. Use a lubricant specified for the ambient conditions for the pump and drive.

Lubricate the packing boxes on pumps weekly (if applicable), using the lubricant specified on the drawings or in the supplier's instructions.

5.2.2.1.4 Valves

Valves that have bearings should be lubricated monthly, using the materials specified in the supplier's instructions. If the valves use packing, the packing should be lubricated as recommended in the supplier's instructions.

5.2.2.2 Operational Inspections

Table 5-8 summarizes the required inspections to be performed on recirculating water systems during plant operation and notes their frequency. The table can be used to develop checklists for periodic inspections. Additional information on inspection of the various items is presented in Sections 5.2.2.2.1 through 5.2.2.2.11.

Table 5-8
Operational Inspections: Recirculating Water Systems

Item	Daily	Weekly	Monthly	Quarterly
Air cylinders/leakage			X	
Air cylinders/operation			X	
Compressed-air system filters, traps	X			
Control valves/leakage			X	
Hydraulic cylinders/leakage			X	
Hydraulic cylinders/operation			X	
Hydraulic pump/oil level		X		
Hydraulic pump/accumulator			X	
Pumps/body			X	
Pumps/drive		X		
Pumps/packing boxes		X		
Settling tank/operation			X	
Sumps/operation		X		
Surge tank/operation		X		
Valves/operation			X	
Valves/wear				X

5.2.2.2.1 Air Cylinders

To ensure proper operation, inspect the various air cylinders monthly for leakage. Any leakage in the packing of a double-acting cylinder can usually be detected by a flow of air along the shaft. Sluggish action of the cylinder can be the result of internal leakage or a malfunctioning solenoid valve. If a solenoid valve malfunctions, there is usually a continuous flow of air from the vent port. If an air cylinder operates sluggishly, determine the cause and correct the condition.

5.2.2.2.2 Compressed-Air System

Filters and traps should be inspected daily. Any material found in them should be removed to protect air-controlled equipment from plugging or malfunctioning.

5.2.2.2.3 Control Valves

Each control valve should be inspected monthly for leakage to ensure proper operation of the equipment controlled by the valve. If a control valve leaks, the equipment moves slowly and may creep from its fixed position. A leaking control valve should be repaired or replaced.

5.2.2.2.4 Hydraulic Cylinders

The operation of a hydraulic cylinder should be observed monthly and inspected for leakage. Internal leakage causes a cylinder to operate sluggishly. Other causes of sluggish operation by a cylinder are 1) leakage in a control valve and 2) low hydraulic pressure.

- Inspect each cylinder for leakage and other possible causes of sluggish operation. Determine the cause of sluggishness, and correct the condition. Repair or replace any worn part.

5.2.2.2.5 Hydraulic Pump

If there is a hydraulic pump, its operation should be observed weekly. If pump pressure is not within the limits shown on the supplier's drawings, the control switches should be recalibrated. The oil level in the system should be checked weekly. If the oil is below the specified level, it should be replenished.

5.2.2.2.6 Hydraulic System Accumulator

Check the hydraulic accumulator monthly for leakage and loss of pressure. If there is a loss of pressure, the accumulator should be replaced or recharged. Refer to the supplier's instructions for the correct procedure.

5.2.2.2.7 Pumps

In some systems, the timing of the valves that control flow to or from certain pumps is critical. If the valve timing is incorrect, the pump can be subject to shock loadings.

Inspect the pump body monthly for cracks. If it is cracked, contact the system supplier regarding the timing of the system valves.

Inspect the pump drive weekly for loose or damaged belts. Any loose but undamaged belt should be re-tensioned. If even one belt is damaged, the entire set of matched belts must be replaced. Refer to the supplier's instructions for the correct tensioning procedure.

Pump packing boxes should be inspected weekly for leakage. Any leaking packing boxes should be tightened according to the supplier's recommendations.

5.2.2.2.8 Settling Tank

Observe the operation of the settling tank at least monthly. A heavy carry-over into the overflow trough, when there has been no change in the water flow through the system, can indicate a malfunction in the sludge removal system. Schedule an inspection of the tank at the earliest opportunity to determine the cause of the carry-over.

5.2.2.2.9 Sump(s)

Observe the operation of the sump(s) weekly. A water level overflowing or higher than the design level indicates a problem, such as an imbalance in the water transfer rate, a malfunction in the agitating system, or pump wear. Schedule an inspection of the sump and pump as soon as practical to determine the cause of the problem.

5.2.2.2.10 Surge Tank

Observe the operation of a surge tank weekly. A high ash concentration in the water can result from carry-over from the settling tank, malfunction of the sludge removal system, or wear in the baffling of the tank. Schedule an inspection of the surge tank to determine the source of the suspended solids.

Observe the water level in a surge tank weekly. Refer to the system instructions for the correct water levels under various operating conditions. If the surge tank frequently overflows or requires a substantial flow of makeup water, the level controller may require adjustment. Refer to the instruction manual for the correct adjustment of the water level.

5.2.2.2.11 Valves

Inspect the system valves monthly for proper operation. If the action is sluggish, inspect the operating unit, including the valve air cylinder, hydraulic cylinder, and motor operator. If the valve has a motor operator, inspect the operator for corrosion or wear. Replace any worn or corroded parts of the drive. Refer to the valve operator manual for details on repairs.

Inspect the valve quarterly or as directed by the instructions for internal wear. In some cases, a valve must be inspected more frequently because of the material being handled. Experience determines the necessary frequency of inspections for valves in high wear locations.

Repair or replace a valve when it is worn. Following any internal inspection of a valve or repairs to its operator, readjust the valve as directed by the drawings or instructions.

5.2.2.3 Outage Inspections

Table 5-9 summarizes the inspections that should be performed on recirculating water systems at each scheduled outage and notes their purposes. This table can be used to develop a checklist of the needed inspections, each of which is described briefly in the text section referenced.

Table 5-9
Outage Inspections: Recirculating Water Systems

Item	Section	Inspection Purpose
Hydraulic pump	5.2.2.3.1	Accumulator/wear Body/wear Drive/wear Impeller/wear
Pumps	5.2.2.3.2	Body/corrosion, wear Drive/wear Impeller/wear
Settling tank	5.2.2.3.3	Agitating nozzles/wear Ash accumulations Baffle/wear Overflow weir/wear
Sumps	5.2.2.3.4	Agitating nozzles/wear Ash accumulations
Surge tank	5.2.2.3.5	Agitating nozzles/wear Ash accumulations Baffle/wear
Valves	5.2.2.3.6	Wear

5.2.2.3.1 Hydraulic Pump

The pump(s) should be inspected for wear and the internal clearances between the impeller and the body checked. If the clearances are greater than those specified in the manufacturer's instructions, any worn part should be replaced. Shafts and seals should also be inspected for wear or damage and any damaged or worn parts replaced.

Refer to the manufacturer's drawings and instructions for detailed information on inspection and repair procedures.

Inspect the pump drive for worn bearings, worn or damaged belts, and worn sheaves on the pump and motor. Replace any worn or damaged parts. If even one belt is worn or damaged, the entire set of belts must be replaced. Refer to the manufacturer's drawings and instructions for the correct procedure for installing and tensioning the belts.

Inspect the accumulator for wear and leakage and replace any worn parts or the accumulator itself. Check the accumulator pressure: if it is low, it should be recharged. Refer to the instructions for the correct method of recharging.

5.2.2.3.2 Pumps

The pump(s) should be inspected for wear and corrosion and the internal clearances between the impeller and the body checked. If the clearances are greater than those specified in the manufacturer's instructions, any worn part should be replaced. Shafts and seals should also be inspected for wear or damage, and any damaged or worn parts should be replaced. Refer to the manufacturer's drawings and instructions for detailed information on inspection and repair procedures.

In some systems, the timing of the valves that control flow to or from certain pumps is critical. If the valve timing is incorrect, the pump can be subject to shock loadings.

Inspect the pump body for cracks. If it is cracked, contact the system supplier regarding the timing of the system valves. If pump parts are corroded, contact the pump manufacturer regarding parts fabricated from corrosion-resistant material that suits the existing conditions.

Inspect the pump drive for worn bearings, worn or damaged belts, and worn sheaves on the pump and motor. Any worn or damaged parts must be replaced. If even one belt is worn or damaged, all belts must be replaced. Refer to the manufacturer's drawings and instructions for the correct procedure for installing and tensioning the belts.

Inspect the packing boxes for leakage and wear; replace any leaking or worn packing. Refer to the pump supplier's instruction manual for the correct procedure.

5.2.2.3.3 Settling Tank

Inspect all agitating nozzles for proper sludge removal and wear. Refer to the supplier’s drawings and system instructions for nozzle size and allowable wear. Replace any worn nozzles, ensuring proper alignment according to the supplier’s drawings.

Inspect the bottom of the tank for accumulations of ash or sludge. The presence of accumulations indicates that the sludge-removal system is not functioning correctly. Review the operating instructions for the sludge-removal system to ensure that it is correctly adjusted and operated, and contact the system supplier for any required assistance.

Inspect the overflow weir for ash accumulations in the bottom of the trough and remove any that are present. A major ash accumulation indicates a high carry-over of ash, which results from a change in the water flow characteristics of the system. If the water flow in the system has changed, contact the system supplier for recommendations on correcting the carry-over problem.

5.2.2.3.4 Sumps

All agitating nozzles used for ash removal must be inspected for wear. Refer to the drawings and system instructions for the nozzle sizes and allowable wear. Replace any worn nozzles, ensuring that they are correctly aligned according to the vendor's drawings.

Inspect the bottom of the sump for accumulations of ash or sludge. The presence of accumulations indicates that the system is not functioning correctly. Review the system operating instructions to ensure that it is correctly adjusted and operated, and contact the system supplier for any required assistance.

5.2.2.3.5 Surge Tank

Inspect for wear all agitating nozzles used for sludge removal. Refer to the drawings and system instructions for the nozzle sizes and allowable wear. Replace any worn nozzles, ensuring that they are correctly aligned according to the vendor's drawings.

Inspect the bottom of the tank for accumulations of ash or sludge. The presence of accumulations indicates that the sludge-removal system is not functioning correctly. Review the operating instructions for the sludge-removal system to ensure that it is correctly adjusted and operated, and contact the system supplier if assistance is required.

Inspect the inlet and baffle system for wear, and repair any worn part. A mineral deposit can reduce flow through the outlet, thus reducing the system capacity.

Inspect the tank for mineral deposits, especially the outlet of the recirculating pumps. Remove any deposits found. If a major chemical deposit is present, it may be necessary to perform additional inspections between outages while the plant is operating and remove such deposits.

5.2.2.3.6 Valves

Inspect the valve operator, which can be an air cylinder, hydraulic cylinder, or motor operator. Repair or replace a cylinder that has internal wear. If the valve has a motor operator, inspect it for corrosion or wear. Any worn or corroded parts of the drive should be replaced. Refer to the manual of the valve operator for details on repairs.

Inspect each valve for internal wear, and repair any worn valve. After repairs, readjust each operator as specified in the drawings or the system instructions.

5.2.3 Mechanical Bottom Ash Systems

One main advantage of the MBAS is its simple maintenance requirements. Generally, lubrication and visual inspections are sufficient between scheduled outages. Regular inspections allow for the timely replacement of worn parts before major repairs become necessary. In addition, maintenance and repairs can usually be carried out by plant personnel rather than by specialist technicians.

Safety

When working on or inspecting a bottom ash tank or the equipment in a bottom ash system, observe all plant safety rules. Review the supplier's instruction manuals for safety precautions concerning specific items of equipment.

5.2.3.1 Lubrication

Table 5-10 summarizes the MBAS lubrication requirements. The table can be used as the basis for checklists of lubrications for each component at required intervals. Additional information is provided in Sections 5.2.3.1.1 through 5.2.3.1.7.

Table 5-10
Lubrication Items: Mechanical Bottom Ash Systems

Item	Frequency of Lubrication			
	Daily	Weekly	Monthly	Quarterly
Bearings, belt conveyor (if any)		X		
Bearings, chain idler		X		
Bearings, conveyor drives		X		
Bearings, takeup		X		
Conveyor drive fluids change				(six months)
Compressed-air system lubricators	X			
Crusher drive			X	
Crusher motor/drive fluids			X	
Crusher motor/drive fluids change				X
Crusher bearings and seals			X	
Pumps		X		

5.2.3.1.1 Belt Conveyor Bearings

If there is a belt conveyor to transport ash from the submerged conveyor tank, the shaft and idler bearings should be greased at approximately weekly intervals.

5.2.3.1.2 Chain Conveyor Bearings

Idler bearings on a submerged chain conveyor should be greased at approximately weekly intervals, using waterproof EP grease, preferably lithium-based. The bearings should be accessible for greasing from outside the tank.

5.2.3.1.3 Chain Conveyor Drives

Bearings, chains, sprockets, and couplings at the chain conveyor drive should be lubricated approximately weekly. At the same time, the drive should be inspected for wear.

5.2.3.1.4 Compressed-Air System Lubricators

Lubricators on the compressed-air system should be inspected daily and refilled to the specified level.

5.2.3.1.5 Conveyor Drive Fluids

Fluid levels in the chain conveyor drives and belt conveyor drives (if any) should be checked weekly. Fluid should be drained and refilled approximately every six months.

5.2.3.1.6 Crusher Drive

The oil level of the crusher drive should be checked monthly and the oil replenished if the level is low.

Lubricants of the crusher motor and drive should be changed quarterly or according to the cycle shown in the supplier's instructions. Use the correct lubricant for the ambient temperature conditions.

Crusher seals and bearings should be lubricated monthly with the recommended lubricants. Do not overlubricate the seal. Overlubrication can cause a braking effect on the shaft, which could result in overheating and/or stalling of the crusher.

5.2.3.1.7 Mechanical Pump Drives

Bearings and other items requiring lubrication should be lubricated on a weekly or monthly basis as recommended in the supplier's instructions. This applies to sludge-removal pumps, cooling water pumps, high-pressure pumps, and flocculant pumps (if used).

5.2.3.2 Operational Inspections

Table 5-11 summarizes the MBAS inspections that should be performed during plant operations and notes their frequency. This table can be used to develop a checklist of periodic inspections.

See Sections 5.2.3.2.1 through 5.2.3.2.17 for supplementary information on inspection of the various items.

Table 5-11
Operational Inspections: Mechanical Bottom Ash Systems

Item	Daily	Weekly	Monthly	Quarterly
Ash tank overflows/temperature		X		
Ash tank refractory cooling water supply	X			
Ash tank seal trough overflow temperature		X		
Belts, conveyor (if so equipped)		X		
Belt conveyor drives		X		
Belt conveyor idlers		X		
Chain, conveyor		X		
Chain, conveyor drives		X	X	
Chain, conveyor idlers		X		X
Chain, conveyor shafts		X		
Chain, conveyor wear surfaces			X	
Chain wash-water flow		X		
Compressed-air system filters, traps	X			
Control valves/leakage		X		
Crusher rolls	X			
Crusher drive chain/sprockets			X	
Crusher housing/wear plates			X	
Crusher seals/leakage		X		
Heat exchanger/fouling			X	
Mechanical pump drives			X	
Mechanical pumps		X		
Plate clarifier/fouling		X		

5.2.3.2.1 Ash Tank Overflow

The temperature of the ash tank overflow should be checked weekly. The water temperature should not exceed the temperature specified on the supplier's drawings (usually 125–140 °F [69–80°C]). If the temperature rises above this, the water flow to the internal cooling sprays as well as any other continuous water input to the hopper should be increased. If the temperature is below that specified on the supplier's drawings, the internal water flow may be reduced to the specified water flow for the hopper.

5.2.3.2.2 Ash Tank Seal Trough

The temperature of the ash tank seal trough should be checked weekly. The water temperature should not exceed the temperature specified on the supplier's drawings (usually 125–140 °F [69–80°C]). If the temperature is above that specified, the water flow should be increased until the overflow temperature is at or below the specified temperature. If the overflow water is below the specified temperature, the water flow may be reduced to the supplier's specified minimum flow rate.

5.2.3.2.3 Compressed-Air System

Filters and traps should be inspected daily, and any foreign material should be removed to protect air-controlled equipment from plugging or malfunctioning.

5.2.3.2.4 Control Valves

Each control valve should be inspected weekly for leakage to ensure the correct operation of equipment controlled by the valve. In most cases, the discharge gates of a dewatering bin are controlled manually. A leaking control valve can cause the gate to creep and leak and should be repaired or replaced.

5.2.3.2.5 Belt Conveyors

On installations that use belt conveyors to transport ash to intermediate or final storage, visual inspections should be made weekly. Inspect the condition of the belting as it passes the tail pulley and of drive and idler bearings and shafts. Note any discoloration due to heat, leaking grease seals, or accumulations of dirt and ash, indicating leaked lubricants.

5.2.3.2.6 Chain, Conveyor

During the first month of operation, the tension of both chains should be checked daily and any slack removed. The frequent checking is required because the initial contact between the links and drive is concentrated on the small areas provided by high spots. As each high spot is worn away by the concentrated load applied to it, the same load is spread over a greater area. When this process is completed, weekly checks are adequate. Eventually, when the total range of the tailshaft takeup has been used, several links should be removed from each chain to allow the bearing takeup units to be reset to their original positions.

Marking either a parallel link or a flight bar on each of the chains makes it easier to ensure that the entire chain has been visually inspected as it passes the tailshaft or an observation point in the lower trough.

5.2.3.2.7 Chain Conveyor Idlers

Chain conveyor idlers in the lower trough should be visible through access panels or inspection openings in the tank's plate work. The idlers in the upper (ash-containing) trough can be inspected only when the trough is empty. In either case, the idlers (especially toothed idlers that positively support the chains) should be inspected weekly for undue wear and physical damage. In every case, good design allows idler bearings to be removed and replaced from the outside of the tank without dismantling or disturbing other components.

5.2.3.2.8 Chain Conveyor Drive Sprockets

Chain conveyor or drive sprockets should be accessible for visual inspection at all times. Inspect weekly for any wear or damage to the teeth that could cause the chain to disengage.

5.2.3.2.9 Chain Conveyor Flights and Wear Surfaces

Chain conveyor flights should be inspected when the chain is inspected. The tailshaft end of the tank is a convenient place to make this inspection. It is essential to inspect every flight bar.

Check the flights for physical damage, including bending, integrity of the chain connections, and undue wear on the intended wear surfaces. Repair or replace any worn part.

5.2.3.2.10 Chain Wash Water

On systems that spray wash water onto the chain just before it engages the drive sprockets, the adequacy of water flow should be checked weekly. Such water supplies should be equipped with flow meters (if the same source of water is also used to purge head and tailshaft seals). Flow switches should be incorporated to give alarms for adequate flows.

5.2.3.2.11 Crusher Roll(s)

Inspect the crusher roll(s) daily for wear and engagement. If the roll(s) and the mating parts have inadequate engagement, the size of particles that pass can increase and cause plugging in a jet pump or damage to the impeller in a mechanical pump. The minimum engagement between the roll(s) and mating parts should be available from the crusher supplier. Roll(s) or mating parts that are worn beyond specifications should be replaced. On some crushers, it is possible to rebuild the rolls with a hard face that is applied by welding. If information on the welding rod to be used and the dimensions of the rebuilt face is not included in the instructions, contact the crusher supplier.

5.2.3.2.12 Crusher Drive Chain and Sprockets

Inspect the crusher drive chain and sprockets monthly for wear and adjustment. An incorrectly tensioned chain could fail prematurely. Refer to the supplier's drawings for the correct tension. Because worn sprockets can allow the chain to disengage from the teeth, any worn sprocket should be replaced.

5.2.3.2.13 Crusher Housing and Wear Plates

Inspect the crusher housing and wear plates monthly for wear. Wear plates that are worn through can expose the crusher housing to wear that causes leakage. If a wear plate is worn badly, it should be replaced at the earliest opportunity.

5.2.3.2.14 Crusher Seals

Inspect the crusher seals weekly for leakage. A leaking seal can allow ash-laden water from the crusher to enter the seals, damaging the crusher shaft (and bearings, if the seal is face-mounted). If a seal leaks, it should be tightened only enough to stop the leak. A seal that is overtightened can act as a brake on the crusher shaft, which can damage the shaft and even cause the crusher to stall. Overtightening also reduces the service life of a seal.

5.2.3.2.15 Heat Exchanger Fouling

If the ash system has heat exchangers for cooling its circulating water, the exchanger should be installed in full-load pairs so that one can be a full-capacity standby unit. Each heat exchanger should be fitted with temperature gauges at both the inlet and the outlet. Noting the temperature differential when the system begins service establishes a benchmark that can be used to indicate heat exchanger fouling by a reduced temperature differential.

Thereafter, the temperature differential should be checked monthly. If there is a decrease in cooling, the standby heat exchanger should be brought on line and the active unit opened for cleaning. Deposits on the heat exchanger surfaces should be removed immediately after the unit is taken out of service. If left to dry for only a few hours, these deposits can set up hard, making their removal much more difficult.

Key Human Performance Point

Deposits on the heat exchanger surfaces should be removed immediately after the unit is taken out of service. If left to dry for only a few hours, these deposits can set up hard, making their removal much more difficult.

5.2.3.2.16 Mechanical Pumps

Inspect the drive of a mechanical pump weekly for loose or damaged belts. Any belt that is loose but undamaged should be re-tensioned. If even one belt is damaged and must be replaced, the complete set of matched belts must be replaced. Refer to the supplier's instructions for the correct tensioning procedure. If the drive is direct connected, check the coupling alignment and lubrication.

The shaft packing boxes should be inspected weekly for leakage. If leakage is found, the packing boxes should be tightened according to the supplier's recommendations. Do not overtighten the shaft packing box.

If a pump drive uses a fluid coupling, a shaft coupling, or a gearmotor, check the fluid levels monthly and replenish the fluid as necessary.

5.2.3.2.17 Plate Clarifier Fouling

If a plate clarifier is used to clean up the overflow from the submerged scraper conveyor, check it weekly for accumulated solids on the parallel plates and at the bottom of the clarifier. The accumulations can be "felt"—water temperature permitting—if good visual inspection is impossible. Any accumulations on the plates should be washed away with a hose jet the next time the system is down.

Accumulations at the bottom of the clarifier indicate that sludge removal is inadequate. Sludge at the bottom of the tank should never be allowed to accumulate to within 1 foot (0.3 m) of the lower parallel plates. Improving sludge removal may require pumping the sludge more frequently or increasing the rate of sludge removal. Consult the supplier of the clarifier if sludge removal is unsatisfactory. Deposits on the clarifier surfaces should be removed immediately after the unit is taken out of service. If left to dry for only a few hours, these deposits can set up hard, making their removal much more difficult.

Key Human Performance Point

Deposits on the clarifier surfaces should be removed immediately after the unit is taken out of service. If left to dry for only a few hours, these deposits can set up hard, making their removal much more difficult.

5.2.3.3 Outage Inspections

Safety

- Never enter an ash tank until the boiler has cooled and all slag has been removed from the tubes to prevent possible injury caused by falling material.
- Never enter an ash tank that has not been removed from beneath the boiler unless another person is stationed outside the tank. This door attendant should be prepared to assist in case of an emergency, with rescue equipment available.
- Never enter such a tank unless there is a positive method of preventing the boiler from being fired.

Most of the operational inspections described in Section 5.2.3.2 should also be made during every scheduled outage. Table 5-12 lists additional MBAS inspections that should be made during each scheduled outage. The table can be used to develop a checklist of needed inspections, each of which is described briefly in the sections referenced.

Table 5-12
Outage Inspections: Mechanical Bottom Ash Systems

Item	Section	Inspection Purpose
Breaker bars	5.2.3.3.1	Physical damage
Belt conveyor	5.2.3.3.2	Wear
Chain conveyor	5.2.3.3.3	Wear
Crusher	5.2.3.3.4	Body/wear, corrosion Cam/wear
		Chain and chain guard/wear
		Rotation-detector/wear
		Seal/wear
		Shaft/wear, corrosion
Flight bars	5.2.3.3.5	Wear
		Corrosion
		Physical damage
		Connections
Heat exchangers	5.2.3.3.6	Fouling
		Corrosion, erosion
Lining, transition section	5.2.3.3.7	Spalling Cracks
Mechanical pumps	5.2.3.3.8	Wear
		Corrosion
		Leaks
Overflows, tank	5.2.3.3.9	Mineral accumulation
		Corrosion

Table 5-12 (cont.)
Outage Inspections: Mechanical Bottom Ash Systems

Item	Reference Section	Inspection Purpose
Plate clarifier	5.2.3.3.10	Fouling
		Corrosion
		Leaks
Seal trough	5.2.3.3.11	Accumulations
		Seal plate/distortion
		Nozzle/wear, alignment
Tank shell	5.2.3.3.12	Leakage
		Corrosion
		Wear
Water-level probes	5.2.3.3.13	Calibration
		Corrosion

5.2.3.3.1 Breaker Bars

On units that have breaker bars of any type (including chains) in the transition section, the breakers should be inspected during every outage for damage caused by falling slag or radiant heat from the boiler (such as warping).

Repair or replace any breaker bars that have been damaged by impact. Use a section with the same size as the original bars for replacement because the transition stays may be unable to withstand the additional load that a heavier section could hold.

If the breaker bars have deflected or warped from exposure to the boiler's radiant heat, consult the supplier about upgrading the material of the bars or possibly water-cooling the breaker bars.

5.2.3.3.2 Belt Conveyor

Installations that have belt conveyors to transport ash to intermediate or final storage should be thoroughly inspected during every outage for the following:

- All drive components–Inspect the head, tail, and any snubber shafts for "wind-up" and/or bending. Inspect keys and keyways for wallowing-out.
- Motors and speed-reducers–Check for lubrication, alignment of shafts, and rigidity of mounting.

- Chains and sprockets–Check for wear, alignment, and fatigue. Remove old grease and oil, and relubricate according to the supplier's instructions.

Search carefully for conditions that accelerate wear on the belting itself. Check the conveyor support structure for corrosion or physical damage that could reduce its integrity.

Check idlers and idler bearings for evidence of seizure, bearing failure, or seal failure. Repair or replace any damaged parts as necessary, and grease all bearings.

Verify the correct functioning of any safety-related equipment, including emergency stop switches.

5.2.3.3.3 Chain Conveyor

The most common failure mode of a chain conveyor is stretching of the chain after the hardened surfaces are worn away. Stretching can cause disengagement from drive sprockets, which could have serious consequences. Inspect each link of the chain for excessive wear, and especially for stretching.

If a chain is replaced or modified in any way (for example, shortening or removing of links), the same change must be made in both strands.

Check the chain-conveyor drive train during every outage. Check the shafts for wind-up and bending, and check keys and keyways for wallowing-out. Check motors and speed-reducers for lubrication, alignment, and fatigue. Remove old grease and oil, and relubricate according to the supplier's instructions.

Check idlers and idler bearings for evidence of seizure, bearing failure, or seal failure. Repair or replace any worn or damaged parts, and grease all bearings. If there is a water purge for idler-bearing seals, verify that the water supply passages are unobstructed.

5.2.3.3.4 Crusher

Inspect the crusher body for wear and corrosion. If the body is worn, it should be repaired (if possible). If repair is not possible, install a new crusher body. Inspect the wear plates and liners for wear and corrosion. Any wear plate or liner that is worn should be replaced. Any part that meshes with the crusher rolls should be replaced when worn beyond its design limits. If information on the maximum allowable wear is not included on the crusher drawings, contact the crusher supplier.

The crusher rolls should be inspected for wear and any cam worn beyond the design limits replaced. If information on the maximum allowable wear is not included on the crusher or roll drawings, contact the crusher supplier. Some rolls can be rebuilt using a hard-surface welding rod.

Contact the crusher supplier for information about whether the roll on the crusher can be resurfaced, the recommended welding rod, and the finished dimensions of a resurfaced roll. Roll wear can be accelerated if ash is not accepted by the crusher as rapidly as it is delivered by the chain conveyor. If ash remains in the crusher, the rolls can churn in stationary ash, which increases wear. To minimize wear on all components, the chain conveyor should operate at the lowest speed that keeps it empty of ash. The recommended variable-speed drive should make it possible to attain this minimum speed.

Inspect the chain drive for wear, alignment, and tension. If the chain is worn, replace the entire chain or the defective links. Check the tension of the chain. Refer to the supplier's drawings for the correct tension. If the chain is not correctly tensioned, it should be re-tensioned to meet the supplier's requirements. Inspect the chain guard for wear. Repair or replace any support that is worn or corroded.

The rotation-detector part(s) on the crusher shaft should be inspected for wear and any worn part replaced. The sensing unit should also be inspected for wear, and any worn part should be replaced. Recalibrate the rotation sensor following the replacement of any part.

The shaft seals should be inspected. If the packing or bearings in the seal are worn, the worn parts should be replaced. The seal should be lubricated as specified by the supplier's drawings. The seal must not be overtightened or overlubricated after repair. Either of these conditions can cause the seal to act as a brake on the shaft, overheating or even stalling the crusher.

Inspect the shaft and the cam support structure for wear and corrosion. Replace any worn part in the cam structure and the shaft if it is worn. If the wear is located near the seals, check the supplier's drawings for instructions on refinishing the journal area. If there are no instructions, contact the supplier for a kit or for instructions on refinishing the shaft. If there is corrosion, contact the crusher supplier for the availability of corrosion-resistant crusher parts suitable for the conditions experienced. Problems with corrosion most commonly affect the crusher body. Bodies made of stainless steel are available from all crusher manufacturers, with type 316 stainless steel most commonly used for this application. Identification of the specific corrodent may indicate another material choice.

5.2.3.3.5 Flight Bars

After the ash tank is emptied and flushed clean, inspect the conditions of the flight bars for wear, physical damage, corrosion, and integrity of the connection to the chain. Repair or replace flight bars as appropriate.

5.2.3.3.6 Heat Exchangers

During every outage, any exchangers used to cool the ash tank overflow water should be cleaned and inspected for erosion and corrosion. Deposits on the heat exchanger surfaces should be removed immediately after the unit is taken out of service. If left to dry for only a few hours, these deposits can set up hard, making their removal much more difficult.

Key Human Performance Point

Deposits on the heat exchanger surfaces should be removed immediately after the unit is taken out of service. If left to dry for only a few hours, these deposits can set up hard, making their removal much more difficult.

The tubes should be brushed and flushed to remove any fouling or deposits. If the heat exchangers have removable tube sheets or removable tube bundles (which allow access to the shell side), these surfaces should be cleaned and inspected. If corrosion or erosion is present, contact the supplier for components fabricated from a material that could better meet the operating conditions.

5.2.3.3.7 Linings, Transition Section

Compared with the refractory lining used in water-impounded hoppers, refractory linings used in transition sections are dry and, in many respects, are subjected to more severe operating conditions. During every outage, this lining should be inspected for damage caused either by falling ash and slag or by the radiant heat from the boiler. If portions of the liner are replaced, the underlying steel must be coated with an asphaltic material. Anchors that are corroded or otherwise defective must be replaced.

5.2.3.3.8 Mechanical Pumps

Inspect the mechanical pumps for wear and corrosion, and measure the internal clearances between the impeller and the body. If the clearances exceed those specified in the manufacturer's instructions, the worn parts should be replaced. Shafts and seals should also be inspected for wear or damage, and any damaged or worn part should be replaced. Refer to the manufacturer's drawings and instructions for detailed information on inspection and repair procedures.

If signs of corrosion are present, contact the pump manufacturer for parts fabricated from corrosion-resistant material that better suits existing conditions.

Inspect the drive for worn bearings, worn or damaged belts, and worn sheaves on the pump and motor. Any worn or damaged parts must be replaced. If even one belt is damaged, the entire set of belts must be replaced. Refer to the manufacturer's drawings and instructions for the correct way to install and tension belts.

Inspect the packing boxes for wear and leakage, and replace any worn packing. Refer to the pump manufacturer's instructional manual for the proper procedure.

5.2.3.3.9 Overflows, Tank

Ash with a high calcium content may cause a mineral deposit that may plug the overflow inlets, preventing the overflows from handling the water flow from the tank. Then the water may overflow through the seal trough. Therefore, any mineral deposits should be removed. If overflow inlets plug between outages, contact the hopper supplier for information on enlarging them.

Inspect the overflow boxes for corrosion. If they are corroded and the pH of the tank water is below 5.5, contact the tank supplier for information on obtaining overflow boxes fabricated from corrosion-resistant material suitable for the conditions experienced. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

5.2.3.3.10 Plate Clarifier

If a plate clarifier is used, it should be inspected at every outage for leakage, corrosion, and accumulations. The tank must be flushed free of any residual material immediately after it is emptied and before the material has set up.

Check any gasketed panels for discoloration that indicates a leak, and replace any faulty gaskets.

Check the tank and support structures for damage that could be caused by corrosion. Carefully inspect columns and tank stays for straightness and plumb.

Check each joint for evidence of leakage. If any weld shows signs of leakage, prepare the steel and re-weld to make it watertight.

Inspect the parallel-plate packs for accumulated material. Inspect the water and sludge outlets for accumulations that could affect the flow of fluid or sludge; remove any accumulation before it hardens.

5.2.3.3.11 Seal Trough

Inspect the seal trough for ash accumulations. If the tank has no access openings to the seal trough, however, inspection may be difficult. In such a case, installing access plates in the seal trough at each of its four corners allows easy inspection. The access openings can be provided by making a cutout at each corner and fabricating a cover plate for each one. The cover plates should bolt to the seal trough and be equipped with gaskets to seal the openings. This work can be performed by plant personnel during an outage.

A major ash accumulation can jam the boiler seal plate. This prevents relief of pressure within the hopper by the water seal, which can damage the seal plate. Any ash accumulation should therefore be removed. A major accumulation of ash indicates that flushing is inadequate. Refer to the system instructions for the flushing requirements. If the flushing operation is manually controlled, flushing may not be performed as frequently as is recommended. Contact the system manufacturer regarding the availability of an automatic flushing system.

Inspect the flushing nozzles for wear and alignment. Replace any nozzles that are worn more than 1/16 inch (1.6 mm) on the diameter. Any nozzles that are replaced must be properly aligned as shown on the supplier's drawings.

5.2.3.3.12 Tank Shell

The chain-conveyor ash tank should be inspected during every outage for leakage, corrosion, and wear. The tank must be flushed clear of any residual material immediately after it is emptied and before there is time for the material to set up.

Check gasketed panels and idler bearing gaskets for discoloration that indicates a leak. Replace any faulty gaskets.

Check the ash tank and support structure for damage that could have been caused by large slag falls that impact the tank. Carefully check columns and tank stays for straightness and plumb.

Check welds for leakage. If there is any evidence of leakage, prepare the joint for welding and re-weld it to be watertight.

Inspect the bottoms of the ash trough and incline for excessive wear. Replace any severely worn area with abrasion-resistant plate or a ceramic lining, as appropriate.

Inspect the bottom of the return trough and any wear strips for excessive wear. Renew or replace as appropriate.

5.2.3.3.13 Water-Level Probes

The seal troughs should be equipped with high-water-level probes to annunciate high water level. The probes should be checked for calibration and if incorrect, they should be recalibrated.

Inspect the probes for corrosion or mineral accumulations that could cause the probe to produce spurious annunciations. If corrosion is present and the pH of the seal trough water is below 5.5, contact the system supplier regarding the availability of a more corrosion-resistant probe.

If there is a mineral accumulation on the probe and the seal-trough water has a pH above 8.5, contact the system supplier regarding the availability of a probe that would resist mineral accumulation.

5.3 Predictive Maintenance Recommendations

A considerable number of the maintenance recommendations detailed in Section 5.2 fall into the preventive maintenance category: performing maintenance routines on a scheduled basis in order to improve overall equipment operation, reliability, and longevity. Predictive maintenance (PDM), on the other hand, uses special monitoring technologies to assess the condition of equipment while it is operating, which enables plant personnel to determine if maintenance or adjustments are needed. Proper use of PDM techniques can help to avoid unnecessary maintenance and identify component problems before they cause equipment damage or unscheduled downtime.

Key O&M Cost Point

Proper use of PDM techniques can help to avoid unnecessary maintenance and identify component problems before they cause equipment damage or unscheduled downtime.

Two PDM technologies—vibration analysis and thermographic analysis—most effectively monitor the type of equipment commonly used in bottom ash systems. Each is explained below, along with typical application techniques, advantages, and limitations.

5.3.1 Vibration Monitoring and Analysis

Vibration analysis can be used to determine the operating condition of rotating equipment, identifying developing problems before they cause serious failures and unscheduled downtime. This can include deteriorating or defective bearings, mechanical looseness, and worn or broken gears. Vibration analysis can also detect misalignment or unbalance before these conditions result in bearing or shaft deterioration. Evaluation of long-term vibration analysis trends can identify poor maintenance practices, such as improper bearing installation and replacement, inaccurate shaft alignment, or imprecise rotor balancing.

Key O&M Cost Point

Evaluation of long-term vibration analysis trends can identify poor maintenance practices, such as improper bearing installation and replacement, inaccurate shaft alignment, or imprecise rotor balancing.

All rotating machinery produces vibrations that are a function of the alignment and balance of the rotating parts. Measuring the intensity of vibration at specific frequencies can provide valuable information about the precision of shaft alignment and balance, the condition of bearings or gears, and the effect on the machine of resonances from housings, piping, and other structures. It is an effective, non-intrusive method of monitoring machine condition during startup, shutdown, or in normal operation.

Vibration analysis is used primarily on rotating equipment such as steam and gas turbines, pumps, motors, compressors, paper machines, rolling mills, machine tools, and gearboxes. Recent advances in the technology now allow limited analysis of reciprocating equipment such as large diesel engines and reciprocating compressors.

A vibration analysis system usually consists of five basic parts: signal pickup(s), a signal-recording device, a signal analyzer, analysis software, and a computer for data analysis and storage. These basic parts can be configured as a continuous on-line system, a periodic analysis system using portable measurement and diagnostic equipment, or a multiplexed system that samples a series of points every few minutes. Hardwired and multiplexed systems are more expensive per measurement point, so the determination of which configuration is more practical and economical will depend on the critical nature of the equipment and the value of continuous or semicontinuous measurement data for that particular application.

Frequency of Analysis

Spot-checking (monitoring a measurement point once per year or less) is used primarily when maintenance or operations personnel detect unusual noises or vibrations and want to determine if a serious problem actually exists. If a problem is detected, additional spectral analyses can be made to define the problem and estimate how long the machine can continue to operate before a serious failure occurs.

Spot-checking can be cost-effective for less critical or balance-of-plant equipment, particularly when budget or manpower is limited. However, its effectiveness relies heavily on someone detecting unusual noises or vibration, a practice that may not be reliable on large or complex machines or in noisy areas of a plant. In addition, by the time the problem is serious enough to cause noticeable noise or vibration, the amount of deterioration or damage may already be considerable.

Another application for spot-checking is as an acceptance test to verify that a machine repair has been performed properly. This analysis can verify proper bearing or gear installation as well as alignment and balancing to the required tolerances.

Additional information can be obtained by monitoring machinery on a periodic basis (for example, once per month or once per quarter). Periodic analysis and trending can provide a more subtle indication of bearing or gear wear, allowing personnel to forecast machine conditions in the near future. This advance notice means that equipment can be repaired during normal machine shutdowns or unit outages, rather than after a machine failure has caused unscheduled downtime.

Long-term vibration analysis can identify improper maintenance or repair practices, including improper bearing installation and replacement, inaccurate shaft alignment, and imprecise rotor balancing.

Long-term trends can also identify improper production practices, such as operating equipment beyond design specifications (that is, at higher temperatures, speeds, or loads). The trends can be used to compare similar equipment from different manufacturers to determine if design benefits or flaws will be reflected in increased or decreased service life and operating or maintenance expenses. Ultimately, long-term analysis can be used as part of an overall program to significantly improve equipment reliability.

Key O&M Cost Point

Ultimately, long-term analysis can be used as part of an overall program to significantly improve equipment reliability.

Equipment reliability can include more precise alignment and balancing, higher quality installations and repairs, and continuously lowering the average vibration level of equipment in the plant.

Advantages/Limitations

Though the costs have been reduced and the ease of use improved significantly over the past five years, vibration analysis is still one of the more complex and expensive PDM techniques. The complexity stems in large part from the relatively subjective nature of interpreting vibration spectra and the difficulty in setting effective alarm limits for a variety of rotating machinery configurations.

The relatively high cost per measurement point is a result of the need for sophisticated electronic instruments to collect, analyze, and store the data; the cost of personnel to collect the data; and the cost of personnel and training to interpret the data. The technique is also limited in its application to rotating machinery, though recent experience exists with reciprocating equipment such as diesel engines and compressors.

For companies willing to make a commitment of manpower and resources, the payback can be considerable. Some companies report being able to accurately identify specific gears failing within a gearbox, substantially reducing the amount of downtime required for troubleshooting and repair. Others have been able to identify and solve complex resonance problems causing damage to shafts, bearings, and couplings.

In spite of the higher cost and complexity, the investment in vibration analysis equipment and manpower is often paid back within the first 18 months to two years. At plants where vibration analysis equipment and personnel are already being utilized on other systems, the incremental cost of monitoring applicable bottom ash equipment will be minimal. For companies with limited budgets, there are a variety of service companies that will perform vibration analysis on a contract basis.

5.3.2 Thermography and Thermographic Analysis

Thermographic analysis provides a high-resolution, noncontact means of monitoring the condition of electrical and electromechanical equipment, roofing and wall insulation, and refractories. Infrared scanners (similar in appearance to video cameras) detect differences in surface temperatures and highlight those differences in black-and-white or color images that are displayed on a television screen. These images can be photographed with conventional films, recorded on videotape, or captured on computer disks or the newer PCMCIA cards. The images, called *thermograms*, are used to analyze patterns of heat gain or loss. Thermographic analysis is an effective PDM tool because mechanical or electrical breakdowns are often preceded or accompanied by changes in operating temperatures.

Key O&M Cost Point

Thermographic analysis is an effective PDM tool because mechanical or electrical breakdowns are often preceded or accompanied by changes in operating temperatures.

This information can be particularly important in electrical machinery where circuits and connections may show no visible signs of deterioration until moments before a complete failure. Thermographic analysis can also detect cracks or deterioration in roof or wall insulation and refractories, which can increase heat loss or reduce the efficiency of production processes. The infrared camera can also be used in reverse mode to detect thermally cold spots that indicate vacuum boundary breaches in condensers and turbines.

Infrared scanning is nondestructive and can be performed at a distance for machinery that is difficult or awkward to reach. Because surveys are best performed while the equipment is in operation, there is no need for machine downtime and lost production. In addition to avoiding costly or even catastrophic equipment failures, thermographic analysis can be used to help prioritize repairs prior to planned maintenance, evaluate completed repair work, and check new installations prior to startup.

Frequency of Analysis

Spot-checking is used primarily when maintenance or operations personnel suspect that a problem exists or prior to planned maintenance to identify developing problems and prioritize the work. One advantage of thermographic analysis of electrical equipment is that the scan provides an immediate and quantifiable indication of the temperature difference between a properly functioning circuit, motor, or connection and one that is overheating.

Key O&M Cost Point

One advantage of thermographic analysis of electrical equipment is that the scan provides an immediate and quantifiable indication of the temperature difference between a properly functioning circuit, motor, or connection and one that is overheating.

The technician often can determine the seriousness of the electrical problem without having to review historical patterns or past analyses. This quantitative analysis can also be helpful in determining how long the equipment can continue to operate before a catastrophic failure occurs.

Additional information can be obtained by performing thermographic analysis on a periodic basis (for example, once per year) or after each major overhaul or plant turnaround. Periodic thermographic analysis can provide a more subtle indication of electrical deterioration; bearing, coupling, or belt wear; roof deterioration or leakage; and refractory cracking. This would allow personnel to project acceptable performance for the coming six months or year. Advance notice of developing problems means that they can be resolved or repaired during normal shutdowns rather than before a catastrophic failure occurs. Because developing problems are detected when they are relatively minor, they are usually much less expensive to repair.

Long-term thermographic analysis over several years can be used to identify improper maintenance or repair practices, including improper roof installation or repair, improper bearing or coupling installation or lubrication, improper belt drive installation or alignment, poor quality electrical installation or repair, and improper refractory installation or repair. This information can be particularly useful in reducing or eliminating recurring problems and improving personnel safety.

Long-term trends can also be used to identify improper operating conditions, such as operating equipment beyond design specifications (that is, at higher temperatures, speeds, or loads). The trends can be used to compare similar equipment from different manufacturers to determine if design benefits or flaws will be reflected in increased or decreased service life and operating or maintenance expenses.

Advantages/Limitations

Thermographic analysis has found particular application in scanning large, distant, or hazardous surfaces for temperature variations. These include roofs and walls, oven or high-temperature refractory linings, overhead power lines or cables, high voltage transformers, or electrical connections.

There has been limited application of thermographic analysis in mechanical troubleshooting (for example, identifying equipment such as hot bearings, couplings, and belt drives). Plants usually have separate organizations that perform thermographic and mechanical troubleshooting and historically, the two have had limited interaction. Infrared scanners can only measure the temperature of visible, radiating surfaces; that is, they cannot take readings through glass or metal housings or covers, unless the metal covering is thin enough for secondary heat patterns to appear (which is seldom) or an infrared inspection window has been installed.

Key Technical Point

Infrared scanners can only measure the temperature of visible, radiating surfaces; that is, they cannot take readings through glass or metal housings or covers, unless the metal covering is thin enough for secondary heat patterns to appear (which is seldom) or an infrared inspection window has been installed.

Readings are also affected by the reflective nature of the surface being measured; this reflectivity value must be taken into account when scanning different objects or surface materials.

The equipment cost ranges from moderate to expensive, particularly when many of the more sophisticated options are included. Infrared scanners vary in their accuracy, sensitivity, temperature range, resolution, and portability. Options include a variety of graphic displays, video/audio capabilities, zoom, interchangeable lenses, battery operation, data logger/printer, image storage, and digital outputs. Due to the variety of industrial applications, the cost of infrared scanning equipment can often be recovered in one year or less. At plants where vibration analysis equipment and personnel are already being utilized on other systems, the incremental cost of monitoring applicable bottom ash equipment will be minimal. Companies with limited budgets might consult a service company that will perform thermographic analysis on a contract basis.

Scanner operation is relatively simple; however, interpretation of the scanned images requires a moderate amount of training or experience. Training and certification can be obtained from either the scanner manufacturer or one of several independent certification companies.

6
TROUBLESHOOTING

This section begins with a comprehensive treatment of recommended troubleshooting techniques to accurately and efficiently assess operational and mechanical problems with bottom ash systems. The troubleshooting information is also represented in table format for quick reference. The goals are to inform plant personnel of methods by which they can keep their systems operating at high efficiency and to give designers and plant engineers an idea of the requirements and the potential of the various systems.

The recommended process for solving problems is explained in this section: establishing the existence of a problem, identifying the cause of the problem, and correcting the problem. Troubleshooting success is largely dependent on making keen use of all senses when inspecting equipment. The sequence of events in a given process must be thoroughly reviewed, and the knowledge and experience of the personnel who operate and maintain the equipment should be fully utilized.

Some of the diagnostic and corrective information presented is duplicated in different parts of this subsection. For example, air cylinder malfunctions are the same whether the cylinder operates an ash intake or a line gate. A once-through reader of this manual may find the descriptions in these three sections redundant. This repetition is deliberate, however, to minimize the need for searching among different sections to find the information needed by the targeted user of each section; namely, the person who must troubleshoot a malfunction in such a system.

Where a material or operating upgrade can alleviate a problem, an appropriate recommendation is made. In order to diagnose or troubleshoot a problem, there must be a benchmark of normal performance for a system.

Key Technical Point

In order to diagnose or troubleshoot a problem, there must be a benchmark of normal performance for a system.

This benchmark should be established when the system is new or rebuilt, "tight," and in good operating condition. Usually, this condition occurs just after initial run-in or major unit/equipment outages, when bugs have been eliminated and the system has been fine-tuned by the startup engineer.

6.1 System Operation

6.1.1 System Does Not Start

Note: The diversity of equipment and control schemes available in bottom ash systems makes it difficult to be very specific on causes for failure of a system to start. The following is therefore general information.

The system may have interlocks with associated equipment, including the pyrites conveyor, wet economizer tanks, transfer tanks, transfer sumps, dewatering bins, recirculating systems, and sluice fly ash systems. If any interlocking permissive does not allow the sluice bottom ash system to start, there should be an annunciation.

Grounding within a dc control circuit may cause a malfunction of the controls and prevent the system from starting. Check for grounds in the dc control circuits and repair as needed.

If the circuit breakers or fuses for either the control panel or any of the associated equipment are open, the system cannot start. Close any open circuit breakers, and replace any fuses that have been removed.

If any malfunctions are annunciated when the control panel is energized to start the system, the causes of the annunciations should be investigated and the necessary corrective action taken.

6.1.2 System Stops or Does Not Convey Ash

Note: The diversity of equipment and the variety of control schemes available make it difficult to provide a specific cause for system shutdown or failure to convey ash.

The system can be shut down due to power loss, which appears as a loss of the indicators on the control panel or as a malfunction annunciation. The cause of the annunciation should be determined and the necessary corrective action taken.

Interlocks can cause the system to shut down or stop conveying ash. Typical problems or malfunctions that may or may not be annunciated include crusher malfunction, loss of conveying water pressure, discharge gate malfunction, low water level in transfer tanks or sumps, high ash level in dewatering bins, and recirculating system malfunctions.

Whenever a malfunction is annunciated, determine the cause and take the necessary corrective action.

6.2 Ash Hopper

6.2.1 Ash Hopper Empties Slowly

A worn pump reduces the system capacity and causes the hopper to empty more slowly.

- Check the pump for wear. If it is worn, replace or repair it.

Note: With a jet pump, the system capacity is calculated on the basis of a worn combining tube in the pump. The emptying time should not exceed the value for the tube worn to the diameter used for the system design.

- Contact the system supplier if the worn size is not listed in the system instructions.

Whenever the ash concentration in the slurry is too high, the pump does not accept the full flow from the hopper. If the crusher sound indicates that ash is not passing through the crusher at a normal rate, the probable cause is that the slurry concentration has become too great for the pump.

- Refer to the system instructions for information on the proper use of a diluting spray and the proper method of slurrying the ash before the ash discharge gate is opened. If this information is not included in the instructions, contact the system supplier.

Large pieces of ash or slag can block the discharge gate opening, reducing the flow of ash from the hopper.

- If the gate is frequently plugged by ash or slag, contact the furnace and/or sootblower supplier for assistance in reducing or eliminating large slag falls.

Calcium accumulations in the discharge line can reduce the inside diameter of the line, thus reducing system capacity.

- Check the discharge line for deposits if the ash contains calcium oxide or calcium carbonate. Clean the line as required.

Note: The troubleshooter must also keep in mind whether any fuel changes have taken place. Different fuels may have significantly different ash contents and characteristics, which can affect not only the ash hopper emptying times but bottom ash system performance in general.

6.2.2 Discharge Gate

In most systems, the movement of the gate is regulated by speed-control valves that prevent the gate from opening or closing too rapidly. If the speed-control valves are set beyond the point needed to allow smooth operation of the gate, it will operate extremely slowly.

- Check the settings of the speed-control valves, if used. Readjust for proper control. Refer to the system instructions for the recommended opening and closing rates.

The hopper gate opens or closes slowly if the gate cylinder piston rod is misaligned or bent. This can cause the piston rod to bind, reducing the rate at which the gate can move.

- Check the piston rod and if misaligned, realign it. If the rod is bent, repair as needed.

Low operating pressure in the gate cylinder also reduces the rate at which the gate opens or closes and can allow the gate to creep.

- Check the air or hydraulic pressure that operates the gate. If it is low, take corrective action to provide the correct operating pressure.

If the gate cylinder is operated by air pressure applied to a hydraulic reservoir, a low hydraulic level can change the way that the gate operates.

- Check the fluid level in the hydraulic reservoir. If the fluid is depleted, fill the reservoir to the required level.

If the operating cylinder leaks, the hopper gate can creep away from the open or closed position.

- If the gate creeps, check the operating cylinder for leakage. Repair or replace the cylinder as required.

In some systems with discharge gate limit switches, a creeping gate can stop the conveying operation. This should be an annunciated malfunction.

In a system that uses air pressure applied to a water reservoir to operate the gate, impurities in the water can corrode the gate cylinder, damaging the piston seals.

- Inspect the inside of the operating cylinder for signs of corrosion or mineral buildup. If found, contact the system supplier for recommendations of an oil or hydraulic fluid that can be used instead of water to operate the cylinder without damaging the seals or packing.

A discharge gate will not normally be watertight because of the abrasive material being handled and the resulting problems of creating a sealing surface. The gate can, however, be adjusted for minimum leakage.

- Refer to the gate drawings for instructions on proper gate adjustment.

Some gates use replaceable gate seats and faces to minimize leakage.

- At each outage, inspect the gate, face, and seat for wear. If a part is worn, replace it.

The gate can be attacked by acid in the sluice water.

- If the gate or any other part shows signs of corrosion, check the pH of the water from the hopper. If the pH is 5.5 or below, contact the hopper supplier for assistance in selecting a gate with corrosion-resistant parts to withstand the conditions indicated by the measured pH. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

If the control valve in a manually controlled system leaks, the pressure to the cylinder may be inadequate either to open or close the gate completely or to keep the gate in the fully open or fully closed position.

- Inspect the control valve for leakage or wear. If the valve is leaks or shows wear, repair or replace it.

6.2.3 Solenoid Valve Malfunction, Gate Actuator

Suspended solids, scale, or erection debris in the compressed air supply can plug the solenoid valve diaphragm relief opening and prevent the piloting function from seating the valve. This establishes two air paths in the valve, allowing air to pass to the exhaust and reducing both the pressure and the volume of air flowing to the gate cylinder or reservoir.

- Check the exhaust for airflow. If airflow is found, the valve is not seating correctly. Clean or rebuild the solenoid valve as required.

A solenoid valve can be plugged by paint unless all openings are sealed whenever painting is done near the valve (for sealing the valve, use the original shipping plugs or masking tape). If the interior of the valve has paint in it, the valve must be cleaned and rebuilt.

6.2.4 Gate Enclosure

The discharge gate must empty through a watertight enclosure to direct the flow of ash from the hopper to the crusher and conveyor line. The enclosure must have a pressure relief valve that accommodates the full flow of the jet pump nozzle water. This protects the enclosure if there is a complete plugging of the line or a malfunction of an isolation valve. The pressure relief valve should empty into the hopper to contain the flow of water from the jet pump nozzle. If a line plugs or an isolating valve malfunctions, the water level in the hopper rises. The problem should be annunciated as high water level in the hopper. When the ash system is started, the enclosure is under a vacuum created by the conveying pump until the discharge gate is opened. It is possible for this vacuum to collapse the enclosure.

Key Human Performance Point

When the ash system is started, the enclosure is under a vacuum created by the conveying pump until the discharge gate is opened. It is possible for this vacuum to collapse the enclosure.

- Inspect the pressure relief valve at each outage to ensure proper operation.
- Regularly inspect the vacuum relief valve for proper operation by listening to it when the system is started. There should be an inrush of air until the discharge gate opens. If the vacuum relief valve is malfunctioning, repair or replace it.

The gate enclosure can be attacked by acidic water.

- If the pH of the hopper water is below 5.5, contact the hopper supplier for assistance in obtaining an enclosure fabricated from corrosion-resistant material to withstand the operating conditions. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

If the water pressure of the diluting spray is increased for any reason, the resulting increased turbulence accelerates wear on the enclosure.

- Do not allow the diluting spray to exceed the maximum value recommended by the hopper supplier.

6.2.5 Overflow

Many hoppers have water level probes in their overflows to annunciate high water levels in the hopper.

- Regularly check the calibration of the level probes to ensure that high water levels in the hopper will be annunciated.
- If there are spurious annunciations of high water levels, check the calibration of the probe. If it is incorrectly calibrated, recalibrate it.

The water flow rate to the hopper must be sufficient to quench the ash being collected and to maintain a maximum acceptable internal temperature. The flow rate can vary seasonally if the temperature of the water supply changes.

- Regularly check the water temperature in the overflow weir box. If it exceeds the maximum shown on the hopper control drawings or in the system instructions, increase the internal water flow to reduce the temperature to the specified maximum.
- Measure the flow of water over the weir in the overflow seal box. If the flow exceeds the recommended maximum flow and the temperature is below the specified maximum, reduce the internal water flow to the recommended rate.
- Contact the hopper supplier if the overflow water temperature and flow are not shown on the hopper control drawings or in the system instructions.

The overflow boxes should be inspected for wear, corrosion, and calcium deposits. If there are signs of corrosion, the pH of the overflow water should be measured. If the pH is below 5.5, there may be some acid attack on the material.

- Contact the hopper supplier for assistance in selecting a corrosion-resistant material for the overflow boxes to suit the conditions existing in the hopper. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

When ash contains calcium compounds, they can mix with water and cause a mineral accumulation on the surfaces of the hopper. If the calcium deposits restrict the flow of water through the overflows, the hopper can overfill and the water can overflow through the seal trough.

- At each outage, inspect the overflows for calcium deposits. Remove any that are found.
- If the overflows plug between outages, contact the hopper supplier for recommendations on modifying the overflows to increase the weir area to accommodate the existing conditions.

6.2.6 Refractory Lining Damage

The refractory lining of the hopper can be damaged by the shock of quenching. A quench can occur when a section of the lining is first exposed to the radiant heat of the furnace and then flooded with water (for example, during the refilling operation after a hopper has been emptied). It can also occur if the water curtain is lost and the area at the water level is alternately subjected to cooling and heating by the wave action of the water in the hopper. If one is not already in place, a water curtain should be installed to protect the lining. All ash hoppers should have a water curtain in place to protect the tank lining against radiant heat.

Key Technical Point

All ash hoppers should have a water curtain in place to protect the tank lining against radiant heat.

- Contact the hopper supplier for information and assistance concerning the addition or modification of a cooling water curtain for refractories.

Quenching shock can also occur if the cooling water curtain is interrupted. Sediment accumulations in either the curtain water supply piping or trough can interrupt the flow. The curtain water supply piping or trough must be flushed at least daily. An automatic flushing arrangement should be available from the hopper supplier.

Large pieces of ash or slag falling into the hopper can damage the lining as the material hits the water in the hopper or strikes the hopper lining (if the water level in the hopper is low). In most cases, there is also thermal shock when the hot material strikes the water, heating it rapidly.

- Contact the furnace and/or sootblower supplier for assistance in minimizing slag falls from the boiler tubes.

6.2.7 Seal Trough

A seal plate that is distorted or bent indicates that pressure fluctuations within the hopper are not being accommodated by the seal trough or that mechanical interference may be a problem.

- Inspect the seal trough for ash accumulations that do not allow water flow between the seal plate and the bottom of the seal trough. Remove any ash accumulations found.
- Inspect the seal plate and trough for proper alignment. Repair as needed.

Ash accumulations normally result from failure to flush the seal trough at least daily. An automatic seal trough flushing arrangement should be available, if not already installed.

- Contact the hopper supplier for information on adding automatic seal trough flushing.

During each outage, the seal trough should be inspected for ash accumulations. Any ash accumulations found must be removed. Deep ash accumulations indicate that the flushing operation may be inadequate.

- Contact the hopper supplier for assistance with increasing the effectiveness of the flush cycle.

6.3 Conveyor Line, Sluice

6.3.1 Conveyor Line Leaks

Pipe connections that fail at elbows and cause leakage indicates that the elbows are not properly anchored. There is an impact on the elbows whenever the feed in the conveyor line changes, which changes the discharge pressure. The anchors must be able to withstand the force imparted to the conveyor.

- Contact the system supplier for the kinetic forces that the anchors must withstand if the forces are not shown on the conveyor drawings. Modify the anchors to withstand the forces if they are not designed to do so. Re-tension the anchors if required.

During startup of some systems, water hammer can occur. This may pull the connections apart.

- Refer to the system operating instructions for information on adjusting the water supply valves to minimize water hammer.

Pipeline should be constructed with provisions for draining the water to prevent freezing. Alternatively, a continuous flow of water through the line can be used to prevent freezing in most cases.

Key Technical Point

Pipeline should be constructed with provisions for draining the water to prevent freezing. Alternatively, a continuous flow of water through the line can be used to prevent freezing in most cases.

In extremely cold climates, the water in the pipeline may freeze even with the minimum flow initiated, damaging the connections and the pipe. To prevent freezing in these conditions, the pipeline should be constructed with provisions for draining the system.

Pipe connections that are not properly assembled can fail under the forces imposed during system operation.

- Refer to the connection drawings for the proper method of assembly and the tightening requirements.

Do not overtighten a connection that uses rubber gaskets because this can cause the gaskets to be forced under a flange and damaged.

- If a rubber gasket connection leaks, undo the connection and retighten it until the leakage is stopped. Refer to the connection drawings for tightening instructions. Connections that are subjected to high pressure and turbulent water (typically the connections at the outlet of a jet pump) must have reinforced gaskets to withstand the magnitude of the fluctuating water pressure.

Key Technical Point

Connections that are subjected to high pressure and turbulent water (typically the connections at the outlet of a jet pump) must have reinforced gaskets to withstand the magnitude of the fluctuating water pressure.

If there is a problem with gasket blowout at this location, contact the system supplier for more suitable connection components.

For connections that use locking flange clamps, the clamps must be properly tightened. Because the flange clamps and the pipe are both castings—which have burrs and surface irregularities—the full torque force of the flange bolts can be temporarily withstood by such an irregularity. This prevents the flange from seating properly and allows leakage. Such a connection will not be sustained under impact. After a flange is torqued, strike the head of the torquing bolt sharply several times with a hammer. Afterward, re-check the torque. If the connection has loosened, re-torque the bolt. Repeat this process until there is no loss of torque when the bolt is struck.

Key Technical Point

After a flange is torqued, strike the head of the torquing bolt sharply several times with a hammer. Afterward, re-check the torque. If the connection has loosened, re-torque the bolt. Repeat this process until there is no loss of torque when the bolt is struck.

Conveyor line fittings are subject to wear, which can cause them to leak. To minimize replacement downtime, a highly abrasion-resistant alloy elbow should be used at points of high impact wear. These points include the first elbow after the jet pump and the elbow at the top of the riser where the ash pipe emerges from a pit or trench (if used).

6.3.2 Conveyor Line Plugs

In normal operation, the discharge from a sluice system is nearly constant. Discharge that has an intermittent spurting pattern indicates a pressure buildup that intermittently forces material past an obstruction in the line. Hence, it is likely that there is a plug in the line. The conveyor line must be flushed after each operation to prevent line pluggage.

Key Technical Point

The conveyor line must be flushed after each operation to prevent line pluggage.

If the line is not flushed to remove all of the ash that has dropped out of suspension during conveying, the resulting accumulations can form a base for additional material that drops out of suspension during succeeding operations. This can result in a partial or complete plug developing in the line. A fuel switch that results in different bottom ash characteristics may require that conveying times or velocity be adjusted.

The conveyor line must be flushed for at least twice as long as the time required for ash to travel from the ash hopper to the discharge point. This period (in seconds) equals the quotient of the conveyor line length (in feet) divided by the minimum conveying velocity (feet per second). The conveying velocity is typically 5–7.5 ft/sec (1.5–2.3 m/sec). The lower value should be used to provide a conservative value for the duration of the flush.

Heavy particles, such as pyrites, can fall out of suspension in vertical or angled risers.

- If this problem occurs, contact the system supplier for assistance in increasing the conveying velocity in risers to retain heavy particles in suspension.

When coal with a high calcium content is burned, the calcium oxide in the ash can mix with water and carbon dioxide in the air to form calcium carbonate, or limestone. This tends to accumulate on the walls of the pipe, which reduces the effective diameter of the pipe. Eventually, this causes the equivalent of a pipe plug, which reduces system capacity. The calcium accumulation must be removed by an acid flush or a mechanical pipe-cleaning machine.

6.3.3 Conveyor Line Wear

Because ash is normally conveyed along the bottom of the conveyor pipe, a wear pattern develops in the lower quadrant of the pipe. Regular inspection of the pipe makes it possible to determine when there is appreciable wear. Periodically rotating the pipe in increments of 90 to 120 degrees (1.6 to 2.1 radians) increases the effective life of the pipe.

Ash that falls out of suspension is dragged along the bottom of the pipe.

- Check the jet pump or slurry pump for wear that reduces the conveying velocity and allows ash to drop out in the pipe. Repair the pump as required to keep ash in suspension.

High-density ash increases wear on the pipe. If the ash has a density greater than 60 lb/ft^3 (960 Kg/m^3), contact the system supplier for assistance in adjusting the power of the pump(s) to keep the ash in suspension.

Key Technical Point

If the ash has a density greater than 60 lb/ft^3 (960 Kg/m^3), contact the system supplier for assistance in adjusting the power of the pump(s) to keep the ash in suspension.

If pipe wears at an unacceptable rate, the use of a pipe lined with ceramic, basalt, or some other abrasion-resistant material may increase the service life.

- Contact the system supplier or a supplier of lined pipe for assistance in selecting a suitable alternative pipe and pipe fittings. See Table 4-1 for a comparison of the most commonly used piping materials.

6.4 Crusher

6.4.1 Crusher Does Not Start

Controls

If the system permits both local and main panel operational control, the crusher will not start if it is in the incorrect mode.

- Change the controls to the correct mode.
- Check the crusher motor starter controls for an open circuit breaker or a fuse that has been removed. If there is an open circuit breaker, close it. Replace fuses as necessary.

Many crushers have interlocking equipment with permissive circuits.

- Check the permissive circuits (such as transport nozzle or jet pump nozzle pressure, seal water pressure, or rotation sensor) for continuity. If any circuit is open, determine the reason and take correction action to allow it to close.

Drive

If the motor and drive are not filled with lubricant to the proper level, the crusher may overheat and trip out.

- Check the oil level. If it is below the operating limit, add oil to bring the level to the correct point.

If the motor is single-phasing, it may not start.

- Check connections at the motor; check contactors at the motor control center. Repair as needed.

6.4.2 Crusher Seals

Water at a pressure higher than the maximum static head in the hopper is used to protect the shaft and seals at the point where, in most crushers, the crusher shaft passes through the crusher body. The seal water should flow inward to prevent ash-laden water from flowing outward to the seals. If the water pressure is too high and the water is not of potable quality, it can damage the shaft surface. If the water pressure is too low, the ash from the crusher cavity can reach the seals and cause wear. The pressure of the crusher seal water should be either the value stated on the system drawings or approximately the maximum static head in the hopper plus 5 psig (34.5 kPa).

6.4.3 Crusher Stalls

If the crusher stalls as soon as the sluice gate is opened and continues to stall during the initial emptying of the hopper section, the ash concentration in the slurry from the hopper is probably too high. In this case, the pump may not accept the ash at the rate at which it is flowing. Most pumps accept ash only at the rate at which it can be conveyed.

If ash is not accepted by the pump, it accumulates in the crusher body and the roll(s) will churn it. If the concentration is too high, the crusher can stall.

- Use a diluting spray to dilute the slurry as it is emptied from the hopper into the crusher.
- Use an internal nozzle (usually one placed opposite the hopper sluice gate) to slurry the ash before the sluice gate is opened. Refer to the system instructions for the proper slurrying procedure.

Some material, such as pieces of slag or erection debris, can be difficult for the crusher to fragment and cause it to stall. If the crusher has an automatic rotation sensor, it should automatically reverse a predetermined number of times to clear the stoppage.

- If the system does not have automatic reversal, manually alternate the crusher between reverse and forward operation to try to clear the obstruction. If this is ineffective, the obstruction must be cleared manually. Refer to the system instructions for the recommended method of clearing a crusher obstruction.

If the crusher seals are overtightened or if the seal is overlubricated, the seal can act as a brake on the crusher shaft.

- Do not overlubricate or overtighten the seal. Relieve the pressure if the condition exists.

If motor is single-phasing, it will stall, especially when under load.

- Check connections at the motor and contactors at the motor control center. Repair as needed.

6.4.4 Crusher Stops

The crusher stops if any control interlock opens during operation. The most common causes are low pressure at the transport nozzle or jet pump nozzle, low seal water pressure, sluice gate not completely open, or crusher rotation sensor.

- Check the annunciations for malfunctions. Correct the condition.

If the system does not have annunciations for the listed items, check the system drawings for the permissive circuits. Inspect each item that has permissive interlocks for operation, and correct the condition that caused the interruption.

6.4.5 Crusher Wear

Normal operation causes wear on the crusher rolls. The wear is accelerated if the crusher operates in high concentration slurry.

- Be sure that the slurry from the hopper is diluted for the correct feed to the pump.

Large pieces of very hard material can accelerate wear on the rolls. The most common source of such material is slag that falls from the tubes.

- Contact the furnace and/or sootblower supplier for assistance with minimizing slag accumulations and slag-falls into the hopper.

Wear on the crusher rolls reduces the engagement between the elements used to reduce the material to the required size. Any reduction of the engagement of the elements leads to an increase in the size of the particles discharged from the crusher. This can cause plugging in the mechanical or jet pumps used to transport the material.

- Contact the crusher supplier for information on the minimum engagement (or maximum clearance) required between the elements of the crusher for correct operation. Change the worn element whenever the engagement falls below the design minimum.

Because acid can attack the crusher, the pH of the water in the hopper should be checked. If the pH of the water is below 5.5, there is a high probability of acid attack on the crusher components. The attack increases as the pH decreases. The roll(s) and wear liners are typically made of alloys that are both abrasion- and corrosion-resistant, although the casings are commonly made of less expensive materials.

- Contact the crusher supplier for assistance in obtaining crusher components that can withstand the acid attack at the pH found in the hopper water. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

6.5 Jet Pump

6.5.1 Jet Pump, Low Capacity

It may be difficult to define capacity in a system that uses a jet pump to convey ash from a bottom ash hopper. *Net capacity* is normally defined as the capacity that the system supplier guarantees when the system is sold.

System net capacity is calculated on the basis of an allowable degree of wear in the jet combining tube. The design wear should be listed in the system instructions. For all practical purposes, the system net capacity is given in terms of how much ash the system can convey when the jet pump is in need of replacement. The actual capacity is initially greater than the supplier's rated capacity and then decreases to that conveying rate as the jet pump wears.

- To avoid a misunderstanding when communicating with the supplier about capacity problems, use the emptying time and the conveying rate measured when the jet pump combining tube is worn to the supplier's specified worn diameter.

When the combining tube is worn beyond the supplier's specifications, the system capacity is reduced.

- Inspect the combining tube regularly for wear and pluggage. Replace the tube when it is worn to the specified maximum amount.

The service life of the combining tube should be calculated on the basis of tons (kilograms) of ash handled. Experience gives an average service life in terms of tons of ash conveyed.

When an amount of ash approximately corresponding to the projected lifetime has been conveyed, inspect the combining tube for wear to determine the need for replacement.

If the nozzle water pressure is reduced, this reduces the capacity of the system.

- Check the water pressure from the sluice water pumps. If it is below the design pressure, inspect the pump for wear. Repair or replace as required to restore design pressure.
- After repairs to the sluice-water pumps, check the rotation of the pump. If the rotation is reversed, the pump will not operate properly, and the pressure developed will be lower than design. Correct the rotation if necessary.

Water pressure to the jet pump is normally reduced as the nozzle wears and allows the flow through the nozzle to increase.

Inspect the nozzle regularly for wear. If it wears more than 1/16 inch (1.6 mm) past the design diameter, replace it.

Water pressure to the jet pump can be reduced by wear of the orifices used to control the water flow to the hopper's internal nozzles. When internal nozzles are in use, the increased flow to them reduces the water flow and pressure to the jet pump.

- If the operating characteristics of the jet pump change when the internal nozzles are in use, inspect the orifices in the water supply lines to the internal nozzles. If they are worn, replace them.

If the crusher is worn, it may not reduce all the ash to a size that passes freely through the throat of the combining tube. This can cause formation of a partial plug in the jet pump and reduce its capacity.

- Inspect the inlet of the combining tube for chunks of ash that plug the jet pump, and remove any that are found.
- Inspect the crusher for wear and engagement of the crusher elements. If the elements are worn, replace them.

Any mineral deposit on the walls of the ash conveyor pipe reduces the effective inside diameter of the pipe, which increases the discharge resistance against which the jet pump conveys the ash. The suction head decreases as the discharge resistance increases. If the coal being used produces ash with calcium compounds, the compounds can form chemical deposits on the pipe walls.

- If a chemical deposit is found, it should be removed by acid flushing or with a mechanical pipe-cleaning device.

6.5.2 Jet Pump, Slow Feed

There is a distinct difference between slow feed to the jet pump and low capacity.

Key Technical Point

There is a distinct difference between slow feed to the jet pump and low capacity.

Slow feed occurs during the initial emptying of a hopper section and can improve as the section empties. Low capacity refers to a reduction in the rate at which ash is conveyed and remains consistent during the entire hopper emptying operation.

Slow ash feed to the jet pump may be caused by the concentration of ash in the slurry. The jet pump requires a specific concentration of ash to operate correctly. The inlet suction of a jet pump decreases as the resistance head increases. A high concentration of ash in the slurry increases the resistance head in the conveyor line. The reduced suction head reduces the amount of ash that the pump accepts at the inlet.

Slow feed increases the amount of ash in the crusher (because it is not being accepted by the jet pump). This condition can cause the crusher to stall and to annunciate the problem if the crusher is equipped with a rotation sensor. Crusher wear increases if this condition persists.

If there is fine ash in the hopper, the ash at the bottom can compact as the load in the hopper increases. When the hopper gate is opened, the ash discharged can be almost dry. To avoid this, and to improve the rate at which the jet pump accepts the ash, the ash should be slurried before the hopper gate is opened. This can be done by using the internal hopper nozzles before opening the gate.

- Refer to the system instructions for information on slurrying before opening the gate.
- In some cases, it is necessary to allow the nozzle to operate during the initial emptying of the hopper section. Contact the system supplier for assistance in making any control changes that may be required.

The use of a diluting spray pipe in the enclosure is recommended for diluting the ash flow to ensure that it is accepted by the jet pump. The diluting spray is a pipe with holes in it that can add 100–150 gpm (6.3–9.45 l/sec) at a low water pressure in the 50-psig (345-kPa) range.

If a diluting spray is installed but not in use, it should be used to improve operation.

If there is a problem with slow feed to the jet pump and a diluting spray is not installed, contact the system supplier for assistance in installing one.

6.5.3 Jet Pump Test

When the combining tube is worn to the diameter specified by the system supplier as the worn condition, the pressure in the sluice line should be measured at a point, downstream from the pump, that is free from turbulence induced by fittings. This should be done at a time when the conveyor has a normal ash loading. This pressure should be recorded for reference.

- After changing combining tubes in the jet pump, periodically measure the pressure at the same point in the conveyor line as the reference pressure. When the pressure drops to the reference pressure, inspect the combining tube for wear.

6.5.4 Jet Pump Wear

The ash conveyed causes normal abrasive wear on the jet pump components. The jet pump should be inspected regularly for wear and any worn parts replaced.

Incorrect water pressure and flow into the jet pump can cause cavitation; the turbulence associated with cavitation increases abrasive wear on the pump. If there is a change in the conveyor length, discharge elevation, or the general routing, the power requirements for the pump can change.

- Contact the system supplier for assistance in recalculating the jet pump requirements.

Before installing either a combining tube or nozzle in the jet pump, the item should be inspected to ensure that it is the proper size. If the size of the combining tube or the nozzle is incorrect, jet pump operation will be adversely affected.

The nature of the ash affects the service life of the jet pump. If the service life is unsatisfactory, contact the system supplier for information on the availability of parts manufactured from a more abrasion-resistant alloy or manufactured with an abrasion-resistant lining to minimize the frequency of part replacement. Alloys such as 27% chrome, Ni-Hard, and others are available from various manufacturers, depending on the site-specific operating conditions. Acidic water reduces the service life of the jet pump body.

Key Technical Point

Acidic water reduces the service life of the jet pump body.

- Check the pH of the hopper water. If the pH is below 5.5, contact the system supplier for the availability of components better suited to existing conditions. Type 316 stainless steel is commonly used for this application, but identification of the specific corrodent may indicate another material choice.

Nozzle wear increases as the amount of suspended solids in the ash sluice water increases. Most system suppliers have nozzles with abrasion-resistant inserts available.

6.6 Mechanical Slurry Pump (Centrifugal)

6.6.1 Mechanical Slurry Pump, Low Capacity

If the pump is worn, the system capacity is reduced.

- Check the pump discharge pressure and if it is low, inspect the pump for wear. Repair the pump as required and replace any worn parts.

A change in either the length of the conveyor line or the discharge elevation changes the conveying requirements of the pump. If the conveyor line routing, length, or discharge elevation has been changed, contact the system supplier for assistance in recalculating the pump speed and power requirements.

If the crusher is worn, it may not reduce all the ash to a size that passes freely through the pump impeller. This can either plug the pump or damage the impeller or casing, reducing the pump's conveying capacity.

- Inspect the pump for chunks of ash that plug the pump impeller, and remove any particles found.
- Inspect the crusher for wear and engagement of the crusher elements. If the crusher elements are worn, replace them.

Any mineral deposit on the walls of the pipe reduces the pipe's effective inside diameter. This increases the discharge resistance against which the mechanical slurry pump conveys the ash. The suction head decreases as the discharge resistance increases. If the ash contains calcium compounds, they may form a chemical deposit on the pipe walls.

- If there is a chemical deposit on the pipe, it should be removed by acid flushing or with a mechanical pipe-cleaning device.

If the pump's rotation is incorrect, the capacity of the pump is reduced.

- Before starting the pump (either initially or after any repairs), check the pump rotation. If incorrect, correct the rotation before operating the pump.

Loose or damaged belts in the pump drive reduce the power transmitted to the pump and thus the capacity of the pump.

- Inspect the drive belts. Re-tension loose belts that are undamaged. Replace damaged belts in matched sets only. Refer to the drive instructions for the proper procedure for tensioning the belts.

6.6.2 Mechanical Slurry Pump, Slow Feed

Slow feed to the mechanical slurry pump is distinctly different from low capacity. Slow feed occurs during the initial emptying of a hopper section and can improve as the section empties. Low capacity refers to a reduction of the rate at which ash is conveyed and remains constant during the entire hopper-emptying operation.

Slow feed of ash to the mechanical slurry pump may be due to the ash concentration in the slurry (the mechanical slurry pump requires a specific ash concentration in the slurry to operate correctly). In a mechanical slurry pump, the inlet suction drops as the resistance head increases. A high ash concentration in the slurry increases the resistance head in the conveyor line, which reduces the suction head. This in turn reduces the flow of ash to the pump suction.

Slow feed increases the amount of ash in the crusher (because it is not being accepted by the mechanical slurry pump). This condition can cause the crusher to stall and to annunciate the problem if the crusher is equipped with a rotation sensor. Crusher wear increases if this condition persists.

If the hopper contains fine ash, the ash at the bottom can compact as the hopper fills. When the hopper gate is opened, the ash discharged can be almost dry. To avoid this and to improve the rate at which the mechanical slurry pump accepts ash, the ash should be slurried before the hopper gate is opened. This can be done by water flow through one of the internal hopper nozzles before the gate is opened.

- Refer to the system instructions for information on slurrying before opening the gate.
- In some cases, it may be necessary to allow the nozzle to operate throughout the initial emptying of the hopper section. Contact the system supplier for assistance in making any required control changes.

A diluting spray pipe should be used in the enclosure to dilute the ash and ensure that it will be accepted by the pump. The diluting spray is delivered by a perforated pipe that adds 100–150 gpm (6.3–9.5 l/sec) at low pressure (about 50 psig [345 kPa]).

- If a diluting spray pipe is installed but not used, it should be used to improve the operation of the system.
- If the feed to the mechanical slurry pump is slow and there is no diluting spray pipe, contact the system supplier for assistance with installing one.

6.6.3 Mechanical Slurry Pump Test

At a time when the conveyor has a normal ash loading, the pressure in the sluice line downstream from the mechanical slurry pump should be checked at a location that is free from turbulence induced by bends or fittings. This pressure should be recorded as a reference.

- Periodically take pressure readings at the same point in the conveyor line as the reference pressure measurement. A pressure less than the reference pressure indicates that the pump should be inspected for wear.

6.6.4 Mechanical Slurry Pump Wear

Because the ash conveyed by the mechanical slurry pump causes abrasive wear of the pump components, the mechanical slurry pump should be inspected regularly for wear. Any worn parts should be replaced. Any impediment to the flow into the mechanical slurry pump can cause cavitation.

Key Technical Point

Any impediment to the flow into the mechanical slurry pump can cause cavitation.

The turbulence associated with cavitation can increase abrasive wear of the pump. If there has been a change in the conveyor length, the discharge elevation, or the general routing, the power requirements for the pump can change.

- Contact the system supplier for assistance in recalculating the power requirements for the mechanical slurry pump.

The nature of the ash affects the service life of the pump.

- If the service life is unsatisfactory, contact the system supplier for information on the availability of parts manufactured from a more abrasion-resistant alloy or with an abrasion-resistant lining to minimize the frequency of part replacement.

Acidic water reduces the service life of the slurry pump body and impeller.

- Check the pH of the ash hopper discharge water. If the pH is below 5.5, contact the system supplier for the availability of components suitable for the existing conditions. High chrome alloys are typically used to improve resistance to abrasion and corrosion.

6.7 Line Valves, Sluice

If a line valve leaks, water flows from the line on which the valve is located. In the case of a conveyor branch isolating valve, there can be a flow of water into the hopper gate enclosure. A leaking valve can usually be located by observation.

6.7.1 Butterfly Valves

A butterfly valve that does not close completely causes wear to the valve seat. The resulting leakage accelerates the wear, reducing the service life of the valve.

- Before installing a new butterfly valve, or following repairs to the valve, adjust the stroke of the air cylinder to ensure that the valve closes completely. Refer to the valve drawings for instructions on proper adjustment of the air cylinder stroke.

A leaking air cylinder, low air pressure, or a malfunctioning solenoid valve can cause a butterfly valve to leak.

Turbulence accelerates wear on a butterfly valve. Normally, turbulence is greatest within six pipe diameters downstream from a change of direction caused by a fitting.

- If a valve is located in a turbulent area, contact the system supplier to determine whether it can be moved to a location free from turbulence.

6.7.2 Totally Enclosed Rotary Sluice Valves

If a totally enclosed rotary sluice valve does not close or open completely, the hole in the slide can be worn into an eccentric shape. Eddies created by the flow of water past the worn section of the slide can accelerate erosion of the slide, body castings, and seats of the valve.

- Before putting into service any totally enclosed rotary slide valve, or following any repairs, adjust the piston rod of the air cylinder to ensure that the slide closes or opens completely. Refer to the drawings of the totally enclosed rotary slide valve for instructions on proper adjustment of the stroke.

An accumulation of ash in the valve cavity can prevent a totally enclosed rotary slide valve from closing or opening completely. The control sequence of the valve should include a flushing arrangement that allows the cavity to drain after conveying stops.

- If a valve has a flushing arrangement and does not close or open completely, contact the system supplier for recommendations on installing a purge seal supply. This uses water at a pressure above the maximum conveying pressure to create a flow from the cavity into the valve, which prevents ash from entering the cavity.

- If the valve has no flushing arrangement, contact the system supplier for instructions on installing one.

Most totally enclosed rotary slide valves use a bearing on the shaft on which the slide moves. A bearing that is not lubricated can seize, limiting the movement of the slide.

- Refer to the manufacturer’s drawings of the totally enclosed rotary slide valve for lubrication instructions. If there is a problem with operation of the slide, inspect the bearing for wear. If worn, the bearing should be replaced.

If the air cylinder leaks, if the air pressure is low, or if the solenoid valve is malfunctioning, the slide may not close or open completely.

6.7.3 Sluice Line Valve Actuators

6.7.3.1 Air Cylinder Malfunction

Air cylinder malfunctions cause sluggish operation of the valve and can prevent the valve from opening or closing completely. This can cause leakage and accelerated wear.

- Check the air pressure and if it is below the specified pressure, correct it.

Internal leakage within an air cylinder (characterized by a flow of air past the piston seal) may prevent an actuator from overcoming the stroking resistance and thus not completely opening or closing a valve.

- To test for leakage while the system is shut down, change the air line from the piston end of the cylinder to the rod end. This puts pressure into the end of the cylinder that would close it. If there is a constant flow of air from the air connection at the piston end of the cylinder, rebuild or replace the air cylinder.

- Remake the air connection to the correct port of the cylinder before operating the system.

A corroded or pitted piston rod can damage the rod end packing of the air cylinder and cause leakage along the piston rod.

- Regularly inspect the piston rod; if it is pitted or corroded, clean or replace it.

Totally dry air increases the friction between the cylinder and the piston and also affects the resiliency of the piston seal. This reduces the life of the seal and causes internal leakage in the air cylinder.

- If the compressed air is dried, a lubricator should be used on the air supply line to the air cylinder(s).

6.7.3.2 Air Pressure

Air pressure below the specified minimum reduces the force developed by the air cylinder. The force may be inadequate to completely open or close the valve.

- Check the air pressure and if it is low, correct it.

6.7.3.3 Solenoid Valve Malfunction

Any suspended solids, scale, or erection debris in the compressed air supply can plug the solenoid valve diaphragm relief opening and prevent the piloting function from seating the valve. This then forms two air paths in the valve and allows air to pass to the exhaust, reducing both the pressure and volume of air to the cylinder.

- When the valve is closed, check the exhaust. A constant flow of air from the valve indicates that the valve is not seating. Clean or rebuild the solenoid valve (as required) to allow the valve to seat correctly.

If the ambient temperature exceeds the coil rating, the solenoid valve can malfunction.

- Check the ambient temperature near the solenoid valve. If it is above the temperature rating for the coil of the solenoid valve, contact the system supplier for assistance in obtaining a coil that has a temperature rating adequate for the actual operating conditions.
- If the cause of the high ambient temperature can be corrected without incurring prohibitive expense, it may be beneficial to pursue this approach. The operation and service life of all equipment in the area would be improved.

Totally dry air can affect the operation of a solenoid valve. The lack of moisture in the air can cause the solenoid valve to pulse at the 60 Hz frequency of the power supply, which causes rapid valve failure.

- Inspect the plunger in the valve. If the air is totally dry, a lubricator should be added to the air supply line. Special construction solenoid valves are available for use with totally dry air if lubricators cannot be used.

Whenever painting is done near a solenoid valve, the valve can be plugged by paint unless all open connections are sealed (seal the valve, use the original shipping plugs or masking tape). If there is paint within the valve, the valve must be cleaned and rebuilt.

The voltage for most solenoid valves must be within ± 10% of the rated voltage.

- Check the voltage at the solenoid valve. If it is not within tolerance, take action to provide the correct voltage.

If the solenoid valve will not actuate, it may be due to a failed or burnt coil or an open power circuit.

- Check any applicable circuit breakers or fuses. If the circuit breaker is open, close it. If a fuse is not in place, replace it. If the circuit breaker is tripped or the fuse is blown, check the solenoid valve to see if the coil is burnt open. Repair as needed.

6.8 Dewatering Bins

6.8.1 Safety

Never enter a dewatering bin, a sump, or a settling, surge, storage, or transfer tank unless the following conditions are met:

- The container is empty.
- The water supply valves are locked in the closed position.

- The valves on any conveyor or recirculating water lines that terminate at the unit are locked in the closed position to prevent any water or material from entering the bin, sump, or tank.
- If pumps are used to convey material from the bin, sump, or tank, the circuit breakers are open and locked and any power fuses removed.
- The atmosphere within the bin has been tested and determined to be safe.
- Another person, stationed outside the bin, sump, or tank, is prepared to assist in case of emergency.

6.8.2 Carry-Over, Solids

Carry-over is a function of turbulence in the dewatering bin and the velocity of the incoming water as it travels from the entry point to the overflow weir. The bin design should balance the water quantity and the bin diameter to limit the flow velocity to a maximum acceptable rate. If the system inflow is increased, the flow velocity can become excessive and retain small particles in suspension. This increases carry-over from the dewatering bin.

- If the system water requirements increase, contact the dewatering bin supplier for assistance in reducing increased carry-over.

Excessive carry-over from the dewatering bin can also result from turbulence in the bin. The turbulence prevents smaller ash particles from dropping out of suspension and settling. Some dewatering bin designs include an anti-turbulence skirt and impact plate unit. If the bin does not have such a unit and the carry-over is unacceptable, the dewatering bin may be improved by adding a skirt around the discharge.

- Contact the dewatering bin supplier for assistance with the design and installation of an anti-turbulence skirt and impact plate unit. If the supplier cannot provide the design, contact a consulting engineer who specializes in ash conveyor equipment.

Some light ash particles can float on the surface of the dewatering bin. These particles can enter the overflow unless there is a floater ring within the bin. This ring, which is designed to trap any floating particles, is located inside the bin near the overflow, extending above and below the normal water level.

- If the bin has no floater ring and there is a problem with floating particles, contact the supplier of the dewatering bin for assistance with fabricating and installing such a ring.
- If there is a floater ring and floating particles are still entering the overflow, it may be necessary to fill the bin with water before conveying ash to it. This prevents floating particles from passing under the ring while the bin is filling.

6.8.3 Dewatering Operation

- Excessive carry-over into the drainpipe during the dewatering process indicates that the ash may not have sufficient time to settle before dewatering. Allow additional time before dewatering begins.

- Refer to the system instructions for the recommended settling time. If this period is insufficient, increase the time in small increments until the adequate dewatering interval is determined. Use this period for resetting the controls.

The dewatering process can be slowed by plugged screens in the dewatering elements. The dewatering rate can be reduced by any ash accumulation at the surface of the screens. Ash at the surface of the screens serves as a filter to retain smaller particles and keep them from passing into the dewatering screens. The dewatering rate is set for normal conditions. If the ash is fine and the dewatering flow is high, the combination can pack the ash at the screens, reducing the water flow.

- Inspect the orifices in the dewatering pipe for wear. If they are worn and oversized, replace them with orifices of the correct size. If the orifices are the correct specified sizes but worn, contact the system supplier for recommendations on changing them.

In the case of very fine ash, it may be necessary to change the dewatering procedure to accommodate the ash. This may involve changing the sequence of the dewatering steps or combining two steps into one. In the latter case, the top two sets of dewatering elements can be used at the same time to reduce the flow rate for individual elements.

- Contact the system supplier for recommendations on modifying the dewatering sequence.

6.8.4 Emptying Problems

Fine ash can pack if it is dewatered too rapidly. Packing can also occur if fine ash sits too long between dewatering and emptying. The operation should be timed to minimize the delay between dewatering and emptying of the bin. In cases where additional moisture can be tolerated during the initial emptying, allowing a small amount of water to remain in the ash helps it to empty. The correct amount of moisture must be determined by experiment.

Ash that has a high calcium content can solidify from the chemical reactions of the calcium compounds mixed with water. If this is the case at a particular plant, the interval between dewatering and emptying of the bin should be minimized.

Ash can accumulate on the bin walls. While the bin is emptying, it may be necessary to use a vibrator to remove the ash from the walls. The vibrator must be used with care because if ash is fine and flowing freely, a vibrator can pack it and stop the flow.

Use a vibrator only if required and only at the end of the operation to remove residual ash from the walls.

6.8.5 Discharge Gate

It is common practice to use the same type of gates on the dewatering bin discharge as those fitted to the bottom ash hopper. In most systems, the movement of the gate is regulated by speed-control valves that prevent the gate from opening or closing too rapidly. If the speed-control valves are closed beyond the point needed to allow the gate to operate smoothly, it will operate extremely slowly.

- Check the settings of any speed-control valves. Readjust if necessary for correct control. Refer to the system instructions for the recommended opening and closing rates.

If the actuating cylinder leaks, the hopper gate can creep from the open or closed position. In some systems with hopper gate limit switches, a creeping gate can stop the conveying operation. This should be an annunciated malfunction.

- If the gate creeps away from the open or closed position, check the operating cylinder for leakage. Repair or replace the cylinder as required.

The hopper gate opens or closes slowly if the gate cylinder piston rod is misaligned or bent. This can cause the piston rod to bind, reducing the rate at which the gate can move.

- Check the piston rod: if misaligned, realign it. If the rod is bent, repair as needed.

Low operating pressure in the gate cylinder reduces the rate at which the gate opens or closes, and also allows the gate to creep.

- Check the air or hydraulic pressure that operates the gate. If it is low, take action to provide the correct operating pressure.

Normally, two systems are used on dewatering bins to power the discharge gates. One uses compressed air over water or oil in a hydraulic reservoir. The other uses a constant-pressure oil system with an accumulator to maintain pressure and an automatic pump to provide flow and additional pressure as required.

If the control valve in a manually controlled system leaks, the pressure to the cylinder may be inadequate to open or close the gate completely or to keep the gate in the fully open or closed position.

Inspect the control valve for leakage or wear. If it is worn or leaking, repair or replace it.

6.8.6 Discharge Gate Solenoid Valve Malfunction

Suspended solids, scale, or erection debris in the compressed-air supply can plug the solenoid valve diaphragm relief opening, preventing the piloting function from seating the valve. This establishes two air paths in the valve, allowing the air or oil to pass to the exhaust and reducing both the pressure and the volume of air or oil to the gate cylinder of the reservoir.

Check the exhaust for a constant flow of air or oil from the valve. If this is found, it indicates that the valve is not seating. Clean or rebuild the solenoid valve as required. Whenever painting is done near a solenoid valve, the valve can be plugged by paint unless all open connections are closed. To seal the valve, use the original shipping plugs or masking tape.

Key Technical Point

Whenever painting is done near a solenoid valve, the valve can be plugged by paint unless all open connections are closed. To seal the valve, use the original shipping plugs or masking tape.

If there is paint in the interior of the valve, the valve must be cleaned and rebuilt.

The voltage for most solenoid valves must be within ± 10% of the rated voltage.

- Check the voltage at the solenoid valve. If it is not within tolerance, take action to provide the correct voltage.

If the solenoid valve will not actuate, it may be due to a failed or burnt coil or an open power circuit.

- Check any applicable circuit breakers or fuses. If the circuit breaker is open, close it. If a fuse is not in place, replace it. If the circuit breaker is tripped or the fuse is blown, check the solenoid valve to see if the coil is burnt open. Repair as needed.

If the gate cylinder is operated by air pressure within a hydraulic reservoir, the operation of the gate can be affected if the hydraulic fluid is depleted.

- Check the hydraulic reservoir for fluid content. If the fluid is depleted, fill the reservoir to the required level.

In a system that uses air pressure above a water reservoir to operate the gate, the condition of the water can corrode the gate cylinder body. In addition, calcium accumulated on the cylinder walls can damage the seals or packing.

- Inspect the inside of the operating cylinder for signs of either condition. If found, contact the system supplier for recommendations on an oil or hydraulic fluid that can be used instead of water to operate the cylinder without damaging the seals or packing.

In a system that uses a closed circulation pumping system, loss of system pressure can cause the gate to creep.

- If the gate creeps, check the solenoid valves for proper operation. If they are malfunctioning, they should be repaired or replaced.
- Check the operation of the accumulator. If it is losing pressure rapidly, inspect it for leaks. Refer to the supplier's instructions for inspection and repair procedures.

A hopper gate is typically not watertight because of the abrasive nature of the material being handled and the problems of creating a sealing surface. The gate can, however, be adjusted for minimum leakage.

- Refer to the gate manufacturer’s drawings for instructions on the proper manner of adjusting the gate.

Some gates have replaceable seats and faces that can be changed to minimize leakage.

- For a gate with replaceable seats and faces, inspect the gate, face, and seat at each outage. Replace any worn parts.

In some cases, the ash is highly abrasive, which accelerates wear of the discharge gate.

- Contact the supplier for information on a gate with a more abrasion-resistant face. Type 316 stainless steel is commonly used in this application.

6.8.7 Level Probe, Dewatering Bin

Some dewatering bins use a level probe to annunciate a high ash level in the bin. The probe is normally a movable arm, powered by an air or hydraulic cylinder, which operates on a timed cycle. Whenever ash rises to a preset level, the arm is stalled by the resistance of the ash to its movement; the stall is then annunciated.

The level probe must have enough power to pass through a small amount of ash but to be stalled by a larger amount. The movement of the arm must be smooth because an uneven starting movement could actuate the stall indicator. The circuit should have a time-delay to minimize spurious annunciations from short stalls caused by an uneven movement of the arm.

- If the arm gives spurious annunciations, check the adjustment to make the movement of the arm as smooth as possible. Refer to the supplier's drawings for instructions.
- Check the setting of the time-delay relay. If not in accordance with the drawings, it should be readjusted.

If the level probe does not have a time delay to minimize spurious annunciations, contact the system supplier for assistance in modifying the circuits to incorporate this feature.

6.8.8 Plugged Screens

The screens in the dewatering elements can be partially plugged by ash that hardens on the surface or by a mineral accumulation. Plugged screens reduce the dewatering rate and must be cleaned.

In both cases, back-flushing the screens while refilling the tank may help to alleviate the problem. This involves filling the dewatering bin with water before the bin begins to operate. For back-flushing, a water supply line is connected to the drain piping and is used to fill the bin. The reverse flow may remove some of the ash and/or mineral deposits.

- If the dewatering bin has no back-flush connection, contact the system supplier for information on installing one.

If material that is plugging the screens cannot be removed by a back-flush, it is necessary to remove the screens for cleaning. Most screens on dewatering elements can be replaced. If this is the case, a spare set of screens should be purchased to allow plugged screens to be readily replaced with clean ones. The plugged screens can then be cleaned on an available-time basis rather than as an emergency operation.

Because most screens are fabricated from stainless steel, they can be cleaned either manually or using an acid bath. In selecting an acid cleaner (such as muriatic acid), be sure that the solution used does not attack the screen material. After the screens are cleaned, they can be stocked for use when the set in service plugs and requires cleaning.

6.9 Recirculating Water Systems (Surge and Settling Tanks)

The components of most recirculating systems include a bottom ash hopper, hopper sump, drain sumps, settling tank, surge tank, and dewatering bins. There are also options such as wet economizer systems, mill-rejects systems, transfer tanks, and other items. In a system with such a variety of equipment, controls, pumps, and other items, it is difficult to provide a universal troubleshooting guide. The following lists a few items that should be common to all systems.

When a recirculating system begins operation, it is essential to establish the water balance. The total water in the settling and surge tanks should be adequate to allow the system to operate without adding water, except to offset losses by evaporation and allow all the equipment to operate without overflowing the surge tank.

- Refer to the system operating instructions for the proper levels in all the equipment used during startup.

If the ash contains calcium, deposits can form in the system and the piping. Check the pH of the water while the system is operating. If the pH is 9.0 or above, there is a high probability of problems with calcium deposits.

- Contact a water treatment consultant for recommendations on minimizing problems with calcium deposits.

When a pump and valve must operate in sequence in a recirculating system, it is essential to time the sequence as specified on the design drawings and in the instructions. In some cases, the pump can experience a shock loading if either the startup or shutdown timing of the pump and the related valve is incorrect.

- If there is pump damage, contact the system and/or pump supplier to determine the exact timing sequence for the specific equipment at the plant.

The material that settles in the settling and surge tanks must be removed at frequent intervals to prevent re-entrainment of it in the water flow. If fine ash is carried over from any tank in the system, it may be necessary to increase the frequency of sludge removal from the tank. Alternatively, the carry-over may be from one or both of the dewatering bins.

6.10 Transfer Pumps

Some systems use a combination of propulsion units. A typical combination uses jet pumps to convey ash from the bottom ash hopper to a sump, from which a mechanical pump conveys the ash to the end of the system.

If the transfer sump overflows regularly, the agitating nozzles should be inspected for wear and alignment. Unless the ash is slurried, the mechanical pump will not convey it at the design rate. This can cause the sump to overflow from accumulated ash. If the agitating nozzles are worn or out of alignment, they should be replaced or realigned as necessary to restore correct operation. The sump design drawings and the system instructions should provide information on the nozzle size and alignment.

An incorrect water transfer rate can cause the sump to overflow. The sump may have been designed for the rated capacity of the jet pumps used on the bottom ash hopper. Because the capacity of the jet pump normally is greater than the minimum capacity used for design and given in the system specifications, the sump may be overloaded when the jet pump is new.

- Consult the system supplier for information on the actual maximum conveying capacity of the jet pumps. If it exceeds the capacity of the mechanical pump in the system, consult the system supplier for assistance in correcting the problem.

6.11 Troubleshooting Guidelines

Table 6-1 provides troubleshooting techniques to accurately and efficiently assess operational and mechanical problems with bottom ash systems.

Table 6-1
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
System Operation	6.1.1	System does not start	Interlocks	Check for annunciation. Take corrective action.
			dc control system malfunction	Check for grounding problems in the dc control circuits. Repair as needed.
			Circuit breakers or fuses	Check the circuit breakers. If any are open, close them. If any fuses have been removed, replace them.
	6.1.2	System stops or does not convey ash	Power loss	Determine the cause and take corrective action.
			Interlocks	
Ash Hopper	6.2.1	Ash hopper empties slowly	Pump is worn	Check for wear. Repair or replace as needed.
			Ash concentration in the slurry is too high	Adequately slurry the ash before opening the discharge gate.
			Blockage of the discharge gate opening	Take corrective action to reduce large slag/ash falls.
			Calcium accumulations in the discharge line	Check/clean the line as needed.
Discharge Gate	6.2.2	Discharge gate operates slowly	Speed-control valves	Check settings of the speed-control valves. Adjust as needed.
			Cylinder piston rod is misaligned or bent	If misaligned, realign the piston rod. If the rod is bent, repair as needed.
			Low operating pressure in the gate cylinder	Check/adjust the pressure.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Discharge Gate (cont.)				Check the control valve for leakage or wear. Repair/replace as needed.
			Low hydraulic fluid level	Check the fluid level in the hydraulic reservoir. Add fluid as needed.
		Hopper gate creep	Operating cylinder leaks	Check the cylinder for leaks. Repair or replace as needed.
		Corroded gate cylinder	Impurities in the water	Switch to a suitable oil or hydraulic fluid.
		Excessive gate leakage	Wear	Inspect/adjust the gate. Repair or replace components as needed.
	6.2.3	Solenoid valve malfunction	Suspended solids, scale, or erection debris in the compressed air supply	Clean or rebuild the solenoid valve as required.
Gate Enclosure	6.2.4	High water level in the hopper	Line plugged or an isolating valve malfunction	Inspect the discharge line and valves. Clean/repair as needed.
		Gate enclosure attacked by acidic water	pH of the hopper water is below 5.5	Buffer the hopper water or replace the enclosure with stainless steel.
		Accelerated wear on the enclosure	Excessive diluting spray water pressure	Check/decrease the water pressure.
Overflow	6.2.5	Spurious high water level annunciations	High water level probe malfunction	Check/recalibrate as needed.
		High hopper water temperature	Insufficient water flow rate	Increase the internal water flow.
		Temperature is below the specified maximum	Excessive water flow rate	Reduce the internal water flow.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Overflow (cont.)		Overflow box corrosion	pH is below 5.5	Install stainless steel overflow boxes.
		Overflow plugged by mineral accumulation	Ash contains calcium compounds	Remove calcium deposits and enlarge overflows if needed.
Refractory Lining	6.2.6	Refractory lining damage	Quenching due to loss of water curtain	Check for sediment accumulations in either the curtain water supply piping or trough. Clean/repair as needed.
			Impact	Take corrective action to reduce large slag/ash falls.
Seal Trough	6.2.7	Seal plate is distorted or bent	Pressure fluctuations within the hopper	Inspect the seal trough for ash accumulations. Remove as needed.
			Misalignment	Check for proper alignment of seal plate and trough. Repair as needed.
		Ash accumulations	Failure to regularly flush the seal trough	Contact the hopper supplier for information on adding automatic seal trough flushing.
			The flushing operation may be inadequate	Contact the hopper supplier for assistance with increasing the effectiveness of the flush cycle.
Conveyor Line, Sluice	6.3.1	The pipe connections fail at elbows and cause leakage	Elbows are not properly anchored	Modify the anchors to withstand the forces if they are not designed to do so. Re-tension the anchors if required.
		The connections pull apart	Water hammer	Adjust the water supply valves to minimize water hammer.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Conveyor Line, Sluice (cont.)		Freezing	Idle, undrained sections during cold weather	Maintain continuous flow or construct with provisions for draining the water.
		Pipe connections fail under the forces imposed during system operation	Connections not properly assembled	See the connection drawings for the proper method of assembly and the tightening requirements.
		Rubber gaskets found forced under a flange and damaged	Overtightened	Undo and retighten to stop leak. Replace the gasket if needed.
Conveyor Line	6.3.2	Pluggage	Inadequate flushing	Flush the conveyor line after each use.
			Inadequate conveying velocity	Increase the conveying velocity.
	6.3.3	Pipe wears at an unacceptable rate	Ash that falls out of suspension is dragged along the bottom of the pipe	Repair/adjust the pump as required to keep the ash in suspension.
			Highly abrasive ash	Pipe lined with ceramic, basalt, or some other abrasion-resistant material may increase the service life.
Crusher	6.4.1	Crusher does not start	Mode setting incorrect	Change the controls to the correct mode.
			Circuit breaker or fuse	Check the crusher motor starter controls for open circuit breaker or removed fuse. Close the breaker or replace the fuse if needed.
			Interlocks	Check the permissive circuits.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Crusher (cont.)			Single phasing of motor	Check motor connections and contactors at the motor control center. Repair as needed.
		Crusher drive is overheating and tripping out	Motor and drive are not filled with lubricant to the proper level.	Check the oil level and refill as needed.
	6.4.2	Shaft damage at seal	Seal water pressure is too high and water is not of potable quality.	Add filtration or change to a clean water source.
			Seal water pressure is too low, allowing ash from the crusher cavity to reach the seals and cause wear.	Pressure of the crusher seal water should be approximately the maximum static head in the hopper plus 5 psig (34.5 kPa).
	6.4.3	Crusher stalls as soon as the sluice gate is opened	Ash concentration in the slurry from the hopper is too high	Dilute the slurry as it is emptied from the hopper into the crusher.
				Slurry the ash before the sluice gate is opened.
			Obstruction	Alternate the crusher between reverse and forward operations to try to clear the obstruction. If unsuccessful, clear manually.
			Crusher seals are overtightened	Relieve the pressure if the condition exists.
			Seal is overlubricated	Relieve the pressure if the condition exists.
	6.4.4	Crusher stops; control interlock opens during operation	Low pressure at either the transport nozzle or jet pump nozzle, low seal water pressure, sluice gate not completely open, or crusher rotation sensor.	Check the annunciation for malfunctions. Correct the condition.
				Inspect each item that has permissive interlocks for operation.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Crusher (cont.)	6.4.5	Accelerated wear	High concentration slurry	Dilute the slurry for the correct feed to the pump
			Large pieces of very hard material	Minimize slag accumulations and slag-falls into the hopper.
			pH of the water is below 5.5	Use corrosion-resistant materials.
Jet Pump	6.5.1	Low capacity	Combining tube wear	Inspect for wear. Replace as needed.
			Inadequate nozzle water pressure	Check the water pressure from the sluice water pumps. Repair or replace as required to restore design pressure. After repairs, ensure that rotation is correct.
				Inspect jet pump nozzle for wear. Replace as needed.
			Jet pump nozzle water pressure is reduced	Inspect the orifices in the water supply lines to the hopper internal nozzles. Replace as needed.
			Combining tube pluggage	Inspect the inlet of the combining tube. Remove pluggage as needed.
				Inspect the crusher for wear and engagement of the crusher elements.
			Chemical deposits on the pipe walls	Remove any chemical deposits that are found.
	6.5.2	Slow feed	High concentration of ash in the slurry	Ash should be slurried before the discharge door is opened.
				Use diluting spray.
	6.5.4	Service life is unsatisfactory	Cavitation	Contact the system supplier for assistance in recalculating the jet pump requirements.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Jet Pump (cont.)			Highly abrasive ash	Install components that are more abrasion resistant.
			Acidic water	Check the pH of the hopper water. If the pH is below 5.5, contact the system supplier for the availability of components better suited to existing conditions.
Mechanical Slurry Pump (Centrifugal)	6.6.1	Low capacity	Pump is worn	Check the pump discharge pressure. If it is low, inspect the pump for wear. Repair as needed.
			The conveyor line routing, length, or discharge elevation has been changed	Contact the system supplier for assistance in recalculating pump requirements.
			Suction pluggage: ash is not reduced to a size that passes freely through the pump impeller	Inspect the pump for chunks of ash that plug the pump impeller. Remove any particles that are found.
				Inspect the crusher for wear and engagement of the crusher elements. If the crusher elements are worn, replace them.
			Mineral deposit on the walls of the pipe	Remove chemical deposit on the pipe by acid flushing or with a mechanical pipe-cleaning device.
			Pump's rotation is incorrect	Correct the rotation before operating the pump.
			Loose or damaged belts in the pump drive	Inspect the drive belts. Re-tension loose belts if they are undamaged. Replace damaged belts only in matched sets.
Mechanical Slurry Pump	6.6.2	Slow feed	High ash concentration in the slurry	Refer to the system instructions for information on slurrying before opening the gate.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Mechanical Slurry Pump (cont.)				Dilute the ash to ensure that it will be accepted by the pump.
	6.6.4	Service life is unsatisfactory	Cavitation	Contact the system supplier for assistance in recalculating pump requirements.
			Highly abrasive ash	Install components that are more abrasion-resistant.
			Acidic ash	Check the pH of the hopper water. If the pH is below 5.5, contact the system supplier for availability of components better suited to existing conditions.
Butterfly Valves	6.7.1	Valve leaks	Improper stroke length	Adjust stroke length.
			Leaking cylinder	Replace seals.
			Low air pressure in the cylinder	Ensure that the air supply pressure is at the proper level.
			Malfunctioning solenoid	Replace/repair the solenoid valve.
		Turbulence	Too close to the cause of turbulence (for example, pipe bed or transition piece)	Move valve away from the cause of turbulence.
Totally Enclosed Rotary Sluice Valves	6.7.2	Valve does not close or open completely	Accumulation of ash in the valve cavity	Flush the valve.
				If the valve has no flushing arrangement, contact the system supplier for instructions on installing one.
			Bearing seized up, not lubricated	Inspect the bearing. Lubricate or replace as needed.
			Air cylinder leak	Inspect/repair as needed.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Totally Enclosed Rotary Sluice Valves (cont.)			Air pressure is low	Check/adjust the pressure.
			Solenoid valve is malfunctioning	Inspect/repair the solenoid valve as needed.
Sluice Line Valve Actuators	6.7.3	Sluggish operation of the valve	Air pressure is low	Check/adjust the air pressure.
			Internal leakage within an air cylinder	Test for leakage while the system is shut down. Repair as needed.
		Leakage along the piston rod	Piston rod is pitted or corroded	Regularly inspect the piston rod. If it is pitted or corroded, clean or replace it.
			Totally dry air	If the compressed air is dried, a lubricator should be used on the air supply line to the air cylinder(s).
		Solenoid valve malfunction	Plug in the solenoid valve diaphragm relief opening	Clean or rebuild the solenoid valve as required.
			Temperature exceeds the coil rating	Contact the system supplier for assistance in obtaining a coil that has a temperature rating adequate for the actual operating conditions.
			Incorrect voltage	Check voltage. Take corrective actions as needed.
			Failed or burnt coil or an open power circuit	Check circuit breakers and fuses. If circuit breakers are open, close them. If fuses are not in place, replace them.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Sluice Line Valve Actuators (cont.)				If circuit breakers are tripped, or fuses are blown, test the solenoid coil to determine if it has failed. Repair as needed.
		Solenoid valve pulsing at the 60 Hz frequency of the power supply	Totally dry air	If the air is totally dry, a lubricator should be added to the air supply line.
Dewatering Bins	6.8.2	Carry-over, solids	Velocity of incoming water	Balance the water quantity with the bin diameter to limit the flow velocity to a maximum acceptable rate.
				If the system water requirements increase, contact the dewatering bin supplier for assistance in reducing increased carry-over.
			Turbulence in the bin	Repair/install the impact plate.
				Install an anti-turbulence skirt unit around the discharge.
			Floaters	Repair/install the floater ring. Fill the bin before conveying ash.
	6.8.3	Carry-over into drain pipe during dewatering is excessive	Ash has insufficient time to settle before dewatering	Refer to the system instructions for the recommended settling time.
		Dewatering process is slow	Plugged screens in the dewatering elements	Inspect the orifices in the dewatering pipe for wear. Replace as needed.
				Contact the system supplier for recommendations on modifying the dewatering sequence.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Dewatering Bins (cont.)	6.8.4	Emptying problems due to ash packing	Dewatering too rapidly/excessive delay before emptying	Time the operation to minimize the delay between dewatering and emptying of the bin.
		Emptying problems due to solidified ash	Ash has a high calcium content	Minimize the interval between dewatering and emptying of the bin.
		Ash accumulations on bin walls	Ash packing	Use a vibrator to remove the ash from the walls.
Discharge Gate	6.8.5	Opening or closing too slowly	Speed-control valves	Check the settings of any speed-control valves. Readjust if necessary for correct control. See the system instructions for the recommended opening and closing rates.
			Misalignment can cause the piston rod to bind	Check the piston rod alignment. If it is misaligned, realign it.
			Low operating pressure in the gate cylinder	Check the air or hydraulic pressure that operates the gate.
			Control valve in a manually controlled system leaks	Inspect the control valve for leakage or wear. If it is worn or leaking, repair or replace it.
			Inadequate hydraulic fluid	Check the hydraulic reservoir for fluid content. Add as needed.
			Corrosion or deposits in water cylinder	Switch to oil or hydraulic fluid.
		Hopper gate creep from the open or closed position	Actuating cylinder leak	Check the operating cylinder for leakage. Repair or replace the cylinder as required.
			Accumulator leak	Inspect/repair as needed.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Discharge Gate (cont.)		Solenoid valve malfunction	Suspended solids, scale, or erection debris in the compressed air supply	Check the exhaust for a constant flow of air or oil from the valve. If this is found, it indicates that the valve is not seating. Clean or rebuild the solenoid valve as required.
			Incorrect voltage	Check the voltage at the solenoid valve. Take corrective action as needed.
			Failed or burnt coil or an open power circuit	Check circuit breakers and fuses. If circuit breakers are open, close them. If fuses are not in place, replace them.
				If circuit breakers are tripped or fuses are blown, test the solenoid coil to determine if it has failed. Repair as needed.
			Solenoid valve plugged by paint	Check/clean as needed.
Level Probe, Dewatering Bin	6.8.7	Spurious high-level alarms	Arm is stalled by the resistance of the ash to its movement	Check the adjustment to make the movement of the arm as smooth as possible.
			Time-delay relay setting	Check/adjust the setting.
Dewatering Bin Screens	6.8.8	Pluggage	Hardened ash on the surface	Back-flush the screens while refilling the tank.
			Mineral accumulations	Clean either manually or by using an acid bath.
Recirculating Water Systems (Surge and Settling Tanks)	6.9	System startup difficulty	Improper water balance	Refer to the system operating instructions for the proper levels in all equipment used during startup.

Table 6-1 (cont.)
Troubleshooting Guidelines

Component	Section	Problem	Probable Cause	Recommendation
Recirculating Water Systems (Surge and Settling Tanks) (cont.)		Calcium deposits in the system and piping	High calcium content in the ash	Contact a water treatment consultant for recommendations on minimizing the problems.
		Pump damage	Pump/valve sequence incorrect	Determine the correct sequence. Adjust as needed.
		Transfer sump overflows regularly	Accumulated ash in transfer sump	Agitating nozzles should be inspected for wear and alignment.
				If agitating nozzles are worn or out of alignment, replaced or realign as necessary to restore correct operation.
			Incorrect water transfer rate	Correctly balance the flow rates of system pumps.

7 TRAINING RECOMMENDATIONS

Training of in-house personnel is a site-specific issue that must be decided by plant leadership, based on the type of equipment used, the type and complexity of maintenance tasks performed by plant personnel, and the inherent challenges and hazards associated with the equipment and location. This guide can be used to form the basis of an effective training program for the most commonly used bottom ash systems and components. The following is a summary of recommended core competencies for plant personnel responsible for operating and maintaining bottom ash equipment.

7.1 Safety Training

7.1.1 Lock-Out/Tag-Out

Before beginning any activity that involves equipment disassembly/entry or direct contact with any portion of the system or its contents that may be dangerous, ensure that equipment is effectively isolated, both mechanically and electrically. Each maintenance or inspection activity must be evaluated to determine the necessary precautions for ensuring personnel safety and equipment protection. These precautions can include:

- Opening circuit breakers/switches and pulling fuses (electrical isolation points)
- Closing valves and dampers (mechanical isolation points)
- Draining fluids and/or relieving pressure from piping and vessels

Be sure to properly document the above with some type of “out-of-service-checklist.” This indicates that the activity is complete and the system can be properly returned to service, posing no danger to personnel.

All isolation points must be tagged or locked so that they will not be inadvertently operated before the equipment is ready to be returned to service.

7.1.2 Confined Space Access

See Section 8.6 for information on confined space access.

7.1.3 Ambient Heat Protection

Operating and maintaining bottom ash systems can involve work in extremely hot ambient conditions, especially when work such as rodding of ash hoppers or slag taps is required directly under the boiler floor area. Personnel assigned these duties must be familiar with the symptoms of heat exhaustion and heat stroke. They should also be trained in the use of methods and equipment designed to minimize these risks.

7.2 Operations Training

7.2.1 System Configuration and Operation

The general information in this guide, along with the system description documents that apply to the specific equipment at a given plant, should be used to give operating and maintenance personnel a thorough understanding of basic system design and operation concepts. This foundation of knowledge provides the perspective necessary to effectively perform tasks such as surveillance, troubleshooting, and adjustments.

7.2.2 System Surveillance

Appropriate personnel should be trained in performing operational inspections. This routine surveillance, along with the necessary adjustments (for example, lubrication routines and tightening of packings) typically comprises a large part of the operator's duties in the bottom ash area.

Other surveillance tasks requiring adequate training include PDM activities, such as the gathering and analysis of vibration and thermographic information.

7.3 Maintenance Training

Most of the skill sets required for maintenance of bottom ash equipment involve general competencies that are used throughout the power plant. Of course, effective maintenance of specialized equipment requires intimate familiarity with the specific components. Such specific and detailed information is best obtained from sources such as manufacturer's drawings and operating and maintenance manuals. Core competencies are required for routine inspection, maintenance, repair, or replacement of the following bottom ash equipment:

- Ash hopper subcomponents, such as seal trough, nozzles, refractory system, and discharge enclosure
- Ash transport piping system subcomponents, such as gaskets, fittings, pipe lengths, expansion joints, line valves, and actuating cylinders
- Clinker grinder subcomponents, such as roll(s), liners, wear plates, seals, shafts, bearings, and drive assemblies

- Control system subcomponents, such as instruments, the conduit, connectors, junction boxes, control panels, and electronic devices
- Dewatering system subcomponents, such as impact plates, level detectors, vibrators, and screens
- Discharge gate subcomponents, such as the gate face, seals, liners, breaker bars, guide angles, rollers, supports, braces, and actuating cylinder
- Centrifugal ash pump subcomponents, such as impellers, liners, casings, seals, belt drives, seals, shafts, and bearings
- Jet pump subcomponents, such as nozzles, bodies, combining tubes, and tailpieces
- MBAS subcomponents, such as breaker bars, drag chains, flights, wear plates and bars, sprockets, seals, shafts, bearings, heat exchangers, and plate clarifiers

Many of the core competencies presented in this section are used in all areas of the plant and therefore require no specialized training for personnel assigned to the bottom ash area. Where specialized training is required, information and training assistance is usually available from the system supplier or component manufacturers.

Key O&M Cost Point

Many of the core competencies presented in this section are used in all areas of the plant and therefore require no specialized training for personnel assigned to the bottom ash area. Where specialized training is required, information and training assistance is usually available from the system supplier or component manufacturers.

8 SAFETY

Operating, inspecting, and maintaining bottom ash systems can expose plant personnel to many potential hazards. These hazards exist elsewhere in the plant, and comprehensive safety procedures must be in place—and followed—for the protection of personnel and equipment. A thorough treatment of all plant hazards would be inappropriate within the scope or intent of this guide. However, common hazards of particular concern due to the nature or location of bottom ash equipment are summarized below, along with recommendations for procedures and equipment features that should be used to minimize the inherent risks. Each person bears primary responsibility for his/her own safety and must utilize all senses and be constantly vigilant and observant in order to enjoy the benefits of a safe working environment.

Key Human Performance Point

Each person bears primary responsibility for his/her own safety and must utilize all senses and be constantly vigilant and observant in order to enjoy the benefits of a safe working environment.

8.1 Electrical Hazards

Live electrical equipment poses the risk of electrical shock or electrocution. Before working on any motor, solenoid, electric actuator, electrical connection, or control system component, be sure to electrically isolate it.

Key Human Performance Point

Before working on any motor, solenoid, electric actuator, electrical connection, or control system component, be sure to electrically isolate it.

The isolation points (for example, breakers, fuses, and switches) must be locked-out or tagged-out, in accordance with a suitable plant procedure. Depending on component voltage and other hazards, protective gear (such as special face shield, gloves, and apron) may need to be worn while racking breakers in and out or removing and replacing fuses.

Improper or inadequate grounding of equipment may cause equipment to operate incorrectly and increases the risk of electric shock—especially in wet or damp areas. In addition, all tools and lights used in damp areas should be double-insulated or plugged into a ground fault circuit interrupter receptacle.

8.2 Eye Protection

In addition to the customary precautions required throughout the plant (for example, always wearing protective eyewear), personnel should be careful of boiler pressure excursions when opening a poke hole. Never look directly at the furnace flame without using a suitable filter, such as a welding glass.

8.3 Hand Protection

The sharp, jagged nature of bottom ash and slag mandates the wearing of protective gloves when working with bottom ash system equipment or performing associated activities such as cleaning or inspection.

A particularly significant hazard exists when manually clearing obstructions from the crusher roll(s) via the discharge enclosure access door. Eroded tube shields can be razor sharp.

Key Human Performance Point

Eroded tube shields can be razor sharp.

When possible, a tool of some kind, such as a metal claw or extractor, should be used to remove the obstruction.

Use extreme caution when using a “poke bar” to remove bridged material or slag from the boiler bottom. The dislodged material can fall on the tip of the bar, ripping it from the worker’s grasp or smashing his/her hands against adjacent steel.

Addition of stainless steel fibers to the gunnite or castable refractory used in bottom ash hoppers is a common approach to stabilizing the monolithic refractory and reducing the tendency of cracked or spalled pieces to detach. When adding these fibers to the refractory mix (during installation), handle them with protective leather gloves or some type of scoop or claw. During inspection, maintenance, or demolition of cured refractory containing these fibers, proper hand protection should also be used.

8.4 High Ambient Temperature

Personnel performing inspection, operating, or maintenance tasks at any location in the plant where the ambient temperature is significantly elevated risk heat exhaustion or heat stroke.

Key Human Performance Point

Personnel performing inspection, operating, or maintenance tasks at any location in the plant where the ambient temperature is significantly elevated risk heat exhaustion or heat stroke.

Bottom ash system tasks that could put personnel at risk include:

- Inspecting or rodding slag taps
- Inspecting for ash bridging at the boiler bottom
- Inspecting or performing maintenance in ash hoppers, bins, or tanks where the temperature is elevated and/or the atmosphere is humid

Fundamental corrective actions that can be taken to improve the ambient working conditions include proper ventilation with cooler air from elsewhere in the plant or outdoors and insulation or repair of any boiler steel or other equipment that may be causing a problem due to radiant or convective heat. Personnel who work in an extremely hot environment should not work alone and should wear a cooling vest to prevent elevations in body temperature.

Key Human Performance Point

Personnel who work in an extremely hot environment should not work alone and should wear a cooling vest to prevent elevations in body temperature.

8.5 Scald/Burn Hazards

Particularly when working under the bottom of the boiler or in the vicinity of piping that carries hot water or steam, personnel must be very cautious and observant in order to avoid any dripping or spraying fluids that may be hot. Such fluids include water, steam, lubricants, flue gas, and heated air. Although it is very unusual, slag can drip from a wet-bottom furnace that has a breach in floor tube membrane. Heavy, insulated gloves should be worn when touching hot surfaces or tools is necessary or likely. A long-sleeved shirt or other protective covering made of heavy cloth (such as a welding jacket) must be worn in areas where incidental contact with hot surfaces is possible.

Key Human Performance Point

A long-sleeved shirt or other protective covering made of heavy cloth (such as a welding jacket) must be worn in areas where incidental contact with hot surfaces is possible.

8.6 Confined Space Access

A confined space is any location that has limited means of ingress and egress and is not designed for continuous human occupancy. Confined spaces common in bottom ash systems include the following:

- Bottom ash hoppers
- MBAS tanks
- Discharge enclosures
- Dewatering bins
- Settling and surge tanks

Plant personnel who are required to enter confined spaces for inspection or maintenance activities should be trained in accepted methods of testing for suitability of ambient conditions, fall protection, confined space monitoring, and rescue.

Key Human Performance Point

Plant personnel who are required to enter confined spaces for inspection or maintenance activities should be trained in accepted methods of testing for suitability of ambient conditions, fall protection, confined space monitoring, and rescue.

Fundamental attributes for safely entering and working in a confined space include the following:

Lock-Out/Tag-Out

All equipment or processes that could cause a hazard within the space must be properly removed from service in accordance with plant procedure. See Section 7.1.1 for information on lock-out/tag-out precautions.

Initial Assessment

Qualified personnel must assess what atmospheric or physical hazards could be expected to exist within the confined space. If necessary, fresh air ventilation of the space can be done to ensure that the ambient temperature and air quality are suitable. Before entry, atmospheric testing for all potential hazards must be performed with the proper instruments to ensure that no such hazards exist. In the case of ash hopper entry, a thorough inspection must be made to determine whether slag or ash accumulations exist on the boiler tubes overhead or in the convection pass area. Any such accumulations must be removed to eliminate the potential hazard of falling debris.

Documentation and Communication

Proper entry forms should be completed and given to the designated supervisory personnel, who will ensure that no actions are taken that would jeopardize the safety of the work within the confined space.

Attendant

An attendant should be posted at the entrance of the confined space and be able to communicate with the entrant(s) to monitor status.

Atmospheric Monitoring

If atmospheric conditions within the space could change, entrant(s) should carry or wear suitable monitoring devices that would sound an alarm if a hazard developed that would necessitate ceasing work and evacuating the space.

Sign In/Out

After necessary work within the confined space is completed, the entrant(s) and attendant should “sign out” and notify the designated supervisory personnel that the space is available for return to service as needed. No further work within the space could then be performed without a re-assessment.

8.7 Hazardous Materials

Depending on the composition of the ash being burned, traces of hazardous chemicals (such as arsenic or heavy metals) may be present in the bottom ash. However, because bottom ash is relatively inert, this situation rarely poses a hazard to personnel. If site-specific conditions result in the ash being hazardous, Material Safety Data Sheet (MSDS) information should be on file at the plant, special handling procedures should be instituted, and training of affected personnel should be performed.

> **Key Human Performance Point**
>
> **If site-specific conditions result in the ash being hazardous, Material Safety Data Sheet (MSDS) information should be on file at the plant, special handling procedures should be instituted, and training of affected personnel should be performed.**

In almost all cases, concerns about hazardous materials are the result of the various lubricants, solvents, paints, and cleaners that are an integral part of maintaining power plant equipment, including the bottom ash systems. In some older systems, asbestos gaskets may be present (although this is unusual). Each plant must thoroughly assess the hazardous materials present on-site, have the necessary MSDS information on file and available to personnel, and take the proper precautions for training, personnel protection, work practices, disposal, and spill prevention/containment.

8.8 Oxygen Displacement

One hazard of particular concern in low-lying areas of the plant, such as ash pits, is the possibility that the atmospheric oxygen may be displaced by heavier gaseous discharge from nearby processes.

> **Key Human Performance Point**
>
> **One hazard of particular concern in low-lying areas of the plant, such as ash pits, is the possibility that the atmospheric oxygen may be displaced by heavier gaseous discharge from nearby processes.**

The most common cause of this type of hazard is a fire protection system that uses carbon dioxide to suppress combustion. If any oxygen displacement hazard exists at a plant, suitable warning signs and alarms must be placed to warn personnel that immediate evacuation of low-lying areas is necessary if a discharge of such a heavy gas occurs. Re-entry of low-lying areas cannot commence until proper ventilation and testing are satisfactorily completed.

8.9 Miscellaneous

- Slipping and tripping hazards are common, due to the often wet and cramped working conditions. These hazardous situations require extra caution and wearing of hard hats to avoid head injuries.
- Hearing protection is required wherever the noise level is excessive, especially within the plant, and in enclosed areas where machinery is operating or loud work is taking place.
- Workplace safety depends in part on the diligence and thoroughness of plant operators when placing equipment in service. All components including hatches, covers, guards, and lubrication levels should be checked in addition to all items on the lock-out, tag-out list. Necessary test runs must be satisfactorily completed before the system is operated.
- Access doors on the side of discharge enclosures are essential for providing access to the top of the crushers for activities such as inspection and clearing of jambs. However, the adequacy of the doors' closure system significantly affects the safety in the ash pit area. If an access door closure fails during the sluicing operation, the entire hopper full of water and ash can be quickly discharged with considerable force into the ash pit. These door closures should be very robust mechanically, and extra caution and diligence should be exercised when fastening the doors closed. Personnel should avoid being directly in front of, or below, such an access door during the sluicing operation.
- At any location where a sluice line leak would cause a particular hazard to personnel or equipment, representative thickness testing of the fittings and lower quadrant should be periodically performed to allow thin portions to be replaced before a leak occurs.

Effective communication among all plant personnel, via radio or other suitable method, significantly enhances general safety. This is especially important during nonstandard operating conditions, such as during inspection or maintenance activities, deslagging, or while placing equipment in or out of service.

Comprehensive labeling of system components, piping, and valves promotes safety, facilitates troubleshooting, and reduces operating and maintenance errors.

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A
POP OUT SUMMARY

Key O&M Cost Point

Page	System	Key O&M Cost Point
3-2	Pulverized Bottom Ash Hoppers	The standard plate material used for bottom ash hoppers and accessories is ASTM A-36 carbon steel, with selective upgrading to stainless steel (type 304, 316, or 316L) as a function of exposure to boiler gases, sulfur content of the coal, and accessibility of the part for repair or replacement.
3-19	Centrifugal Ash Pumps	Ejectors can be serviced more easily, but such service may be required much more frequently than for a comparable centrifugal pump. In addition, offsetting the ease of maintenance of ejectors is the requirement for maintenance of the high-pressure centrifugal pumps supplying impulse water to the ejectors.
3-20	Pipe and Fittings	Plain-end pipe is easier and less expensive to produce than other types and, because the exact length required can be cut from stocked full-length sections, it is more readily available.
3-21	Metallic Pipe and Fittings	Unlined metallic piping systems are commonly used and have the advantages of simple construction and maintenance along with low initial cost.
3-21	Metallic Pipe and Fittings	The lifetime cost of basalt material can often justify the increase in initial cost.
3-22	Plastic Pipe and Fittings	The main advantages offered by nonferrous HDPE pipe material are ease of installation (due to longer, lighter lengths) and longer life (due in part to its resistance to chemical attack).
3-24	Expansion Joints	Sleeve-type and bellow-type expansion joints each have their own advantages. Sleeve-type expansion joints have lower initial costs and are generally more durable. Bellows-type expansion joints are less likely to leak and require less force to operate, which reduces the size (and cost) of pipe anchors.
3-26	Rotary Disc Sluice Valves	Rotary disc sluice valves, once used almost exclusively, have now been largely superceded by slide gates. A rotary disc gate, however, may still be considered whenever cost is a high priority.
3-38	Mechanical Bottom Ash System	The ultimate success or failure of an MBAS depends largely on the life of the chain used. Replace the chains with a matched set on both sides of the ash tank.

Page	System	Key O&M Cost Point
3-43	Recirculating Water Systems	Most plants being built today are required to meet “zero discharge” criteria, which prevent contaminated water from being discharged.
3-46	Mechanical Bottom Ash System	Advantages of the MBAS include the following: low power requirements, no conveying water usage, smaller space requirements, lower headroom requirements (steel savings), elimination of the need for dewatering bins (although these may be replaced by storage silos), and lower capital cost.
3-52	Environmental Considerations	Control system hardware is affected by its environment, which includes temperature, humidity, dust, moisture, electrical noise, and exposure to mechanical abuse.
4-4	Refractory	In order to avoid the cost and outage impact associated with a true heat-cure, users may simply fire the boiler very slowly on initial startup—using ignition fuel only and minimum air flow—to avoid damage to the new refractory and achieve some degree of bonding within the material.
4-4	Seal Troughs/Plates	Although carbon steel is relatively inexpensive and is available as a standard seal trough/plate material from boiler and hopper suppliers, long-term viability in this application is questionable.
4-4	Seal Troughs/Plates	A potentially aggressive environment makes the use of a suitable stainless steel economically justifiable. Type 316 stainless steel provides good service with extended life, making it an economical long-term choice for seal troughs and plates.
5-5	Crushers	A cost-saving best practice is to rebuild crusher rolls rather than replace them when they have worn beyond the manufacturer's specification.
5-66	Predictive Maintenance Recommendations	Proper use of PDM techniques can help to avoid unnecessary maintenance and identify component problems before they cause equipment damage or unscheduled downtime.
5-66	Vibration Monitoring and Analysis	Evaluation of long-term vibration analysis trends can identify poor maintenance practices, such as improper bearing installation and replacement, inaccurate shaft alignment, or imprecise rotor balancing.
5-67	Frequency of Analysis	Ultimately, long-term analysis can be used as part of an overall program to significantly improve equipment reliability.
5-68	Thermography and Thermographic Analysis	Thermographic analysis is an effective PDM tool because mechanical or electrical breakdowns are often preceded or accompanied by changes in operating temperatures.
5-69	Frequency of Analysis	One advantage of thermographic analysis of electrical equipment is that the scan provides an immediate and quantifiable indication of the temperature difference between a properly functioning circuit, motor, or connection and one that is overheating.

Page	System	Key O&M Cost Point
7-3	Maintenance Training	Many of the core competencies presented in this section are used in all areas of the plant and therefore require no specialized training for personnel assigned to the bottom ash area. Where specialized training is required, information and training assistance is usually available from the system supplier or component manufacturers.

Key Technical Point

Page	System	Key Technical Point
3-1	Pulverized Bottom Ash Hoppers	The most common boiler bottom design is a water-impounded bottom ash hopper, which provides the following: a means of continuous removal of ash from the furnace, temporary storage of ash, and a means of transporting ash away from the steam generator.
3-1	Pulverized Bottom Ash Hoppers	A bottom ash hopper should store, as a minimum, the amount of ash that is produced at Maximum Continuous Rating (MCR) during an 8-hour shift, with some extra capacity for safety.
3-2	Pulverized Bottom Ash Hoppers	An optimum storage capacity of the bottom ash tank is in the range of 10 to 12 boiler hours (36 to 43 Ksec) output, with storage capacity for 14 hours (50 Ksec) output considered a practical maximum.
3-2	Pulverized Bottom Ash Hoppers	All but the smallest ash hoppers should be constructed of steel plate at least 3/8 inches (9.5 mm) thick, reinforced and braced to contain a mixture of ash and water at a density of 100 to 120 lbs/ft^3 (1,602 to 1,922 Kg/m^3).
3-3	Lining of Bottom Ash Hoppers	Use a combined thickness of 9 inches (228 mm) of refractory or brick and cement to line the sloped hopper sides.
3-3	Lining of Bottom Ash Hoppers	The system of anchors welded to the inside surface of the hopper side plates to hold hopper refractory must have a minimum (vertical and horizontal) placement of 15-inch (331-mm) centers.
3-4	Refractory Cooling	A water source is located at the top of the refractory wall and supplied with cooling water at the rate of approximately 2 gpm per linear foot (126 ml/sec per 300 mm) to protect the refractory cement from overheating.
3-6	Refractory Cooling	A flow three times the normal trough makeup flow is required to sweep accumulated sediment from the bottom ash tank seal trough.
3-6	Refractory Cooling	Bottom ash tank seal troughs should be flushed at the end of each conveying cycle at a minimum of once per day to prevent sediment buildup.
3-8	Hopper Discharge Doors	The watertight enclosures placed around the discharge doors should be fabricated from plate at least 3/8 inch (9.5 mm) thick to ensure reliability and strength.
3-10	Pressure- and Vacuum-Relief Valves	The pressure- and vacuum-relief valves of the door enclosure must be automated so that their purpose of protecting the equipment and personnel cannot be defeated or manipulated.
3-11	Jetting Nozzles	The maximum effective distance of a slope nozzle from the hopper discharge is generally 13–15 feet (4–4.6 m); if the slope length to the hopper exceeds this measurement, two banks of nozzles should be used.

Page	System	Key Technical Point
3-12	Crushers	On hydraulic pipeline ash conveyors, it is important that the maximum dimension of the ash (or slag) not exceed one-half the inside diameter of either the pipe or the internal pump clearance to ensure that the ash (slag) can be reliably transported without bridging or plugging.
3-15	Crushers	Reversing the roll segments and wear lines of the crusher at their half-life will extend the interval between crusher rebuilds.
3-15	Crushers	Significant usage of filtered water at rates of 5 to 25 gpm (0.32 to 1.5 l/s) while conveying is required to keep the seal air clear of ash.
3-18	Ash Pumps	This unique feature of the jet pump is known *self-regulation*. Self-regulation dilutes the slurry mixture and helps prevent pluggage.
3-18	Ash Pumps	The minimum acceptable amount of nozzle supply water required to properly convey the ash equals 75% of the minimum design flow through the pipe.
3-21	Metallic Pipe and Fittings (Unlined and Lined)	Basalt-lined pipe and fittings for hydraulic ash handling systems are an option for high wear areas that offers gem-like hardness with abrasion resistance. Their disadvantage is their weight and brittleness.
3-22	Couplings	Extra care must be taken in engineering and constructing a piping system with general-purpose couplings to minimize the possibility of coupling disengagement due to expansion, contraction, or impact forces.
3-22	Couplings	Locking-type connections for ash lines must be re-torqued after initial operation.
3-25	Expansion Joints	Expansion joints in ash systems must be fitted with stops to prevent overexpansion or separation. The stops ensure that the entire pipe movement is shared by all expansion joints.
3-27	Rotary Disc Sluice Valves	Ash lines with rotary disc valves must be flushed and purged after each to prevent pluggage.
3-28	Pyrites Hopper for Pulverizers	The function of mill hoppers is twofold: to receive and store mill rejects (pyrites) and to do this in a way that prevents coal-laden air from escaping from the pulverizer.
3-31	Dewatering Bins and Accessories	Dewatering bins should be sized for a combined net storage capacity representing 72 hours (260 Ksec) production of bottom ash at MCR.
3-32	Dewatering Elements	The number of main dewatering elements is, or should be, a function of the bin diameter. The following is recommended: • Diameters to 16 feet (4.8 m): 4 elements at 90 degrees (1.6 radians) • Diameters 16–25 feet (4.8–7.6 m): 6 elements at 60 degrees (1.1 radians) • Diameters 26–35 feet (7.7–12 m): 8 elements at 45 degrees (0.78 radians) • Diameters 36–45 feet (12.1–14 m): 10 elements • Diameters 46–55 feet (14–17 m): 12 elements

Pop Out Summary

Page	System	Key Technical Point
3-32	Dewatering Elements	The main dewatering elements should have screens with diameter or slotted holes from 1/16 to 1/8 inch (1.6 to 3.2 mm) punched on staggered centers 1-1/2 times the diameter (that is, 3/32-inch [2.38 mm] centers for 1/16-inch [1.6 mm] holes and 3/16-inch [4.7 mm] centers for 1/8-inch [3.2 mm] holes) to allow proper dewatering.
3-34	Vibrators	The design of the dewatering bin vibrator control shall be manual with momentary contact. Never energize the vibrators with the discharge door closed or the ash will "pack," resulting in plugging of the discharge.
3-34	Settling Tank	A sizing standard that theoretically results in settling out particles greater that 100 microns (100 micrometers) with a specific gravity of 2.0 or higher is used in designing a settling tank.
3-35	Surge Tank	A cone angle of 45 degrees (0.783 radians) is recommended for surge tanks; 35 degrees (0.61 radians) from the horizontal is considered the minimum.
3-37	Mechanical Bottom Ash System	A variable speed drive train with a turnover of approximately 6:1 is to be used in the MBAS to allow dewatering and volume control.
3-41	Impounded Water Bottom Ash System	Most sluice bottom ash systems are designed to handle 100 tons (91,000 kg) per hour.
3-47	Mechanical Bottom Ash System	Because a mechanical conveyor has a smaller amount of water than a conventional impounded water hopper, the hot ash heats the water and significantly increases the temperature.
3-51	Control Equipment	Water-glycol fluid is used at the bottom ash hopper for its fire resistance properties. Its constant viscosity index provides consistent characteristics over a wide range in temperature.
3-53	Environmental Considerations	The maximum temperature of any assembled panel must be lower than the inside equipment rating. A typical rating for programmable controllers is 0–60°C (32–140°F). Confirm the internal equipment temperature rating and use it as a limiting design criterion.
3-53	Environmental Considerations	Humidity leading to condensation is a particular problem in electronic equipment because it causes high resistance “shorts” or sneak circuits.
4-2	Refractory	The most significant application issues pertinent to ash hopper refractory are refractory material selection, installation method, anchor spacing, surface preparation prior to refractory installation, and curing of installed refractory.
4-2	Refractory	Common misapplications are generally the result of inaccurate or incomplete information given to the refractory supplier or a lack of emphasis on the importance of properly drying (and preferably curing) the refractory before boiler operation resumes.
4-3	Refractory	A minimum setting time of 24 hours (86.4 Ksec) is typically required before the forms are removed.

Page	System	Key Technical Point
4-3	Refractory	Optimum anchor spacing can vary for each hopper refractory system, based on considerations such as refractory thickness and hopper configuration. Ash hopper refractory should be a minimum of 9 inches (229 mm) thick, with anchor placement on 15-inch (381-mm) centers (minimum vertical and horizontal).
4-6	Ash Transport Piping Systems	Ash transport piping should be of increased hardness or wall thickness for the first 10 to 20 pipe diameters downstream of the ash pump, including the first and sometimes the second elbow, depending on layout.
4-6	Ash Transport Piping Systems	An often overlooked fundamental principle of slurry piping layout is the necessity of using only vertical risers at an increase in elevation.
4-7	Crushers	Hardened shaft sleeves are recommended for use in the seal areas of the crusher.
4-8	Control Systems	Ash system instruments, panels, junction boxes, and connectors should be rated NEMA 4 (waterproof) when located in moist areas.
4-8	Dewatering Systems	Size the dewatering bins for a combined net storage capacity representing 72 hours (260 Ksec) of production of bottom ash at MCR.
4-8	Dewatering Systems	To ensure effective emptying of ash, the cone angle should be 55 to 60 degrees (0.96 to 1.0 radians) from the horizontal, and brackets should be provided for mounting four vibrators at 90-degree (1.6-radian) intervals.
4-9	Discharge Gates/Doors	In general, all wear parts of the bottom ash sluice gates and doors should be made of a suitable stainless steel (typically type 316 stainless).
4-10	Centrifugal Pumps	Impellers and wear liners of centrifugal pumps made of high chrome, hardened cast iron provide the best resistance to degradation and therefore the best value.
4-10	Centrifugal Pumps	Belt drives are the best choice for centrifugal bottom ash pumps.
4-11	Jet Pumps	Ejectors are not suitable for pump head requirements of more than 150 feet (45.6 m).
4-11	Mechanical Bottom Ash Systems	Bottom ash chains should be top quality, case hardened, and annealed to achieve a hard wear surface (550–800 BHN [~6.75–7.6 Mohs]). Abrasion-resistant steel, such as AR400, is commonly used for abrasive wear.
5-2	Refractory	Excessive erosion of ash hopper sides can be caused by misaligned flushing nozzles or flush water pressure exceeding the manufacturer's recommendations.
5-3	Refractory	Damage of slag tap refractory can result in rapid erosion of floor tubes in the tap and subsequent tube leaks.
5-3	Seal Troughs/Plates	A polymer coating on the hopper plates and seal troughs will resist corrosion and elevated temperatures.
5-4	Ash Transport Piping Systems	Periodically rotating straight lengths of ash piping in each ash conveyor pipeline is an excellent technique for extending pipe life.
5-5	Ash Transport Piping Systems	A high-impact-resistant lining, such as alumina ceramic or alumina corundum, is used in unlined high chrome metallic pipe in areas closest to the ash pump, including the first downstream elbow.

Pop Out Summary

Page	System	Key Technical Point
5-6	Crushers	Crushers are designed to reduce detrimental effects of binding by using auto-reverse or spring release of the roll(s). A disadvantage is the potential for problems with oversized material in the ash pumps.
5-7	Crushers	The best practice for problematic crusher seal applications is to use a hardened shaft sleeve in the seal areas.
5-9	Centrifugal Pumps	Mitigation of erosion in bottom ash slurry pumps consists mainly of using impellers and casing liners that are cast from extremely hard alloys, such as 27% chrome or Ni-Hard.
5-9	Jet Pumps	Mitigation of erosion and impact in bottom ash jet pumps consists mainly of using components that are cast from extremely hard tough alloys, such as 27% chrome or Ni-Hard.
5-10	Mechanical Bottom Ash Systems	Chrome-nickel alloys and case hardening are commonly used for chain links of MBAS, achieving surface hardness in the range of 550–800 BHN (~6.75–7.6 Mohs).
5-10	Mechanical Bottom Ash Systems	MBAS components with corrosion problems can be replaced with stainless steel fabrications; however, it is preferable and more economical to control pH by injecting appropriate chemicals at the surge tank.
5-70	Thermography and Thermographic Analysis	Infrared scanners can only measure the temperature of visible, radiating surfaces; that is, they cannot take readings through glass or metal housings or covers, unless the metal covering is thin enough for secondary heat patterns to appear (which is seldom) or an infrared inspection window has been installed.
6-1	Troubleshooting	In order to diagnose or troubleshoot a problem, there must be a benchmark of normal performance for a system.
6-7	Refractory Lining Damage	All ash hoppers should have a water curtain in place to protect the tank lining against radiant heat.
6-8	Conveyor Line Leaks	Pipeline should be constructed with provisions for draining the water to prevent freezing. Alternatively, a continuous flow of water through the line can be used to prevent freezing in most cases.
6-9	Conveyor Line Leaks	Connections that are subjected to high pressure and turbulent water (typically the connections at the outlet of a jet pump) must have reinforced gaskets to withstand the magnitude of the fluctuating water pressure.
6-9	Conveyor Line Leaks	After a flange is torqued, strike the head of the torquing bolt sharply several times with a hammer. Afterward, re-check the torque. If the connection has loosened, re-torque the bolt. Repeat this process until there is no loss of torque when the bolt is struck.
6-9	Conveyor Line Plugs	The conveyor line must be flushed after each operation to prevent line pluggage.
6-10	Conveyor Line Wear	If the ash has a density greater than 60lb/ft^3 (960 Kg/m^3), contact the system supplier for assistance in adjusting the power of the pump(s) to keep the ash in suspension.
6-15	Jet Pump, Slow Feed	There is a distinct difference between slow feed to the jet pump and low capacity.
6-16	Jet Pump Wear	Acidic water reduces the service life of the jet pump body.
6-19	Mechanical Slurry Pump Wear	Any impediment to the flow into the mechanical slurry pump can cause cavitation.

Page	System	Key Technical Point
6-26	Discharge Gate Solenoid Valve Malfunction	Whenever painting is done near a solenoid valve, the valve can be plugged by paint unless all open connections are closed. To seal the valve, use the original shipping plugs or masking tape.

Key Human Performance Point

Page	System	Key Human Performance Point
3-9	Pressurized Access Doors (Poke Holes)	Although the vast majority of applications are on balanced-draft units, the pressurized or aspirated poke hole is recommended for maximum operator safety in the event that a boiler puff or transient occurs while an operator is using the observation door or poke hole.
3-49	Ash Handling System Controls	Monitoring the ash handling system and its components for safe and correct operation is of primary importance. Safe operation protects the personnel, the plant, and the ash handling equipment itself.
3-54	Operator Interfacing	Control panels must be designed to benefit the operator and fit into the plant design concept, including cost considerations. Simple interface and visual observation of equipment are critical for operator safety and maximum effectiveness.
5-11	Preventive Maintenance and Replacement Guidelines	Attentive, observant, and conscientious plant personnel are the key to an effective maintenance program.
5-11	Hydraulic Bottom Ash Systems	Whenever performing any work or inspections in the bottom ash hopper or on the equipment used in the bottom ash system, it is essential to observe all plant safety rules.
5-20	Discharge Line Gates or Valves	The operation of the gates and/or valves of a discharge line should be observed monthly.
5-21	Jet Pump	Inspect the combining tube of the jet pump monthly for wear.
5-22	Mechanical Pumps	Inspect the drive of each mechanical pump monthly for loose or damaged belts.
5-57	Heat Exchanger Fouling	Deposits on the heat exchanger surfaces should be removed immediately after the unit is taken out of service. If left to dry for only a few hours, these deposits can set up hard, making their removal much more difficult.
5-58	Plate Clarifier Fouling	Deposits on the clarifier surfaces should be removed immediately after the unit is taken out of service. If left to dry for only a few hours, these deposits can set up hard, making their removal much more difficult.
5-63	Heat Exchangers	Deposits on the heat exchanger surfaces should be removed immediately after the unit is taken out of service. If left to dry for only a few hours, these deposits can set up hard, making their removal much more difficult.
6-5	Gate Enclosure	When the system is started, the enclosure is under a vacuum created by the conveying pump until the discharge gate is opened. It is possible for this vacuum to collapse the enclosure.
8-1	Safety	Each person bears primary responsibility for his/her own safety and must utilize all senses and be constantly vigilant and observant in order to enjoy the benefits of a safe working environment.

Page	System	Key Human Performance Point
8-1	Safety	Before working on any motor, solenoid, electric actuator, electrical connection, or control system component, be sure to electrically isolate it.
8-2	Hand Protection	Eroded tube shields can be razor sharp.
8-2	High Ambient Temperature	Personnel performing inspection, operating, or maintenance tasks at any location in the plant where the ambient temperature is significantly elevated risk heat exhaustion or heat stroke.
8-3	High Ambient Temperature	Personnel who work in an extremely hot environment should not work alone and should wear a cooling vest to prevent elevations in body temperature.
8-3	Scald/Burn Hazards	A long-sleeved shirt or other protective covering made of heavy cloth (such as a welding jacket) must be worn in areas where incidental contact with hot surfaces is possible.
8-4	Confined Space Access	Plant personnel who are required to enter confined spaces for inspection or maintenance activities should be trained in accepted methods of testing for suitability of ambient conditions, fall protection, confined space monitoring, and rescue.
8-5	Hazardous Materials	If site-specific conditions result in the ash being hazardous, Material Safety Data Sheet (MSDS) information should be on file at the plant, special handling procedures should be instituted, and training of affected personnel should be performed.
8-5	Oxygen Displacement	One hazard of particular concern in low-lying areas of the plant, such as ash pits, is the possibility that the atmospheric oxygen may be displaced by heavier gaseous discharge from nearby processes.

B
HYDRODYNAMIC SEAL FOR CRUSHER APPLICATION

This appendix provides information on a patented hydrodynamic rotary seal technology that has been successful in severe downhole drilling environments in the oilfield and has the potential to improve seal life and reliability in crusher applications. In both applications, the rotary seal is exposed to harsh abrasives, large shaft deflections, and frequent start/stop or transient conditions.

Hydrodynamic rotary seals are made of conventional elastomeric material (for example, nitrile) but have a wavy geometry that takes advantage of relative rotation to create a "hydroplaning" action that wedges a thin film of fluid between the seal and the shaft surface. This film eliminates direct rubbing contact and addresses an abrasive wear mechanism that limits the performance and life of conventional packings and seals. Implementation in a crusher stuffing box would require the introduction of clean fluid between two hydrodynamic seals at a pressure slightly higher than the environment, as shown in a simplified schematic arrangement in Figure B-1.

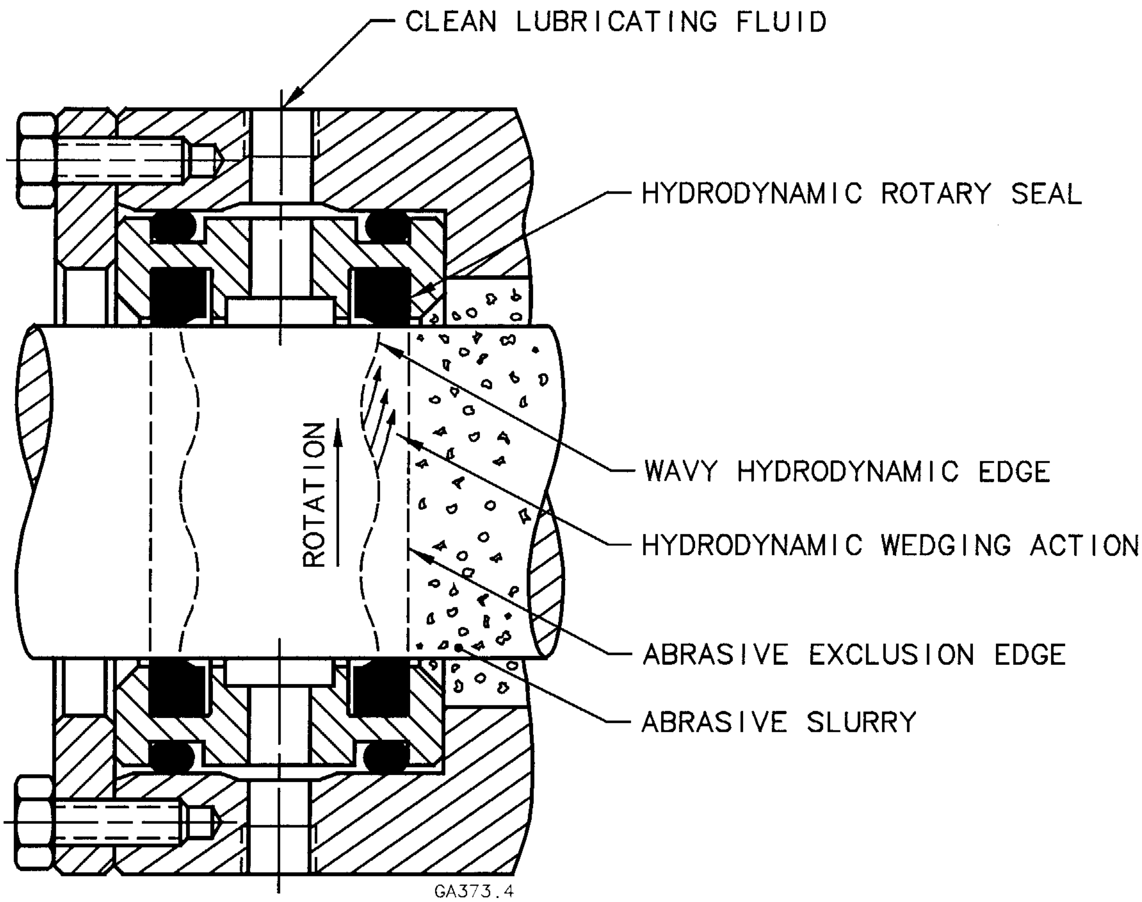

Figure B-1
Typical Seal Installation

SPE/IADC 37627

A Novel High-Pressure Rotary Shaft Seal Facilitates Innovations in Drilling and Production Equipment

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Abstract

This paper describes the principle of operation, laboratory test results, and field performance of a novel high pressure rotary shaft seal and the key features of implementations which have made a number of oilfield drilling and production equipment innovations technically and economically feasible in recent years.

Introduction

By far the most critical element in the equipment used in many drilling and production applications is the rotary shaft seal, which often becomes the limiting component from the standpoint of reliability and economics. Conventional elastomeric and high performance plastic seals, e.g., chevron packings, spring-energized PTFE seals, V-seals, and U-cup seals, are used extensively in such applications. All of these seals rely on the brute force approach and suffer from the same basic disadvantage, i.e., if they're doing a good job of sealing, they're doing an excellent job of *grabbing* the shaft and a poor job of *lubricating* the shaft-to-seal interface. This results in high friction, excessive heat, scorching, blistering, and abrasive wear of the seal material, and severe grooving of the shaft, especially as pressure (P) and velocity (V) increase. The PxV values for the conventional elastomeric and polymeric seal designs are limited to around 200,000 psi x ft/min or less as a result of poor lubrication.

A novel seal that works on a fundamentally different principle of operation **(Fig. 1)** has been developed which overcomes these limitations, thus making a number of drilling and production equipment innovations technically and economically feasible in the recent years. The patented design is based on *hydrodynamic lubrication* principle, which prevents direct rubbing contact between the seal and shaft by forcing a lubricant film at this interface which eliminates wear, dramatically lowers the friction coefficients, and extends the PxV capabilities of the seal to 3.7×10^6 psi x ft/min. Further developments in the seal design and implementation hardware, partially funded by the U.S. Department of Energy, have resulted in key innovations that have extended its pressure capabilities and ability to tolerate the large shaft motions encountered in severe drilling applications and large equipment. The seal has proven its fieldworthiness, reliability, consistency, long life, and cost effectiveness in downhole drilling motor sealed bearing applications, high pressure rotary blowout preventers used in underbalanced drilling, high pressure and high speed swivels, top drives of progressive cavity artificial lift pumps, and is now being introduced into a new generation of advanced rotary steerable systems.

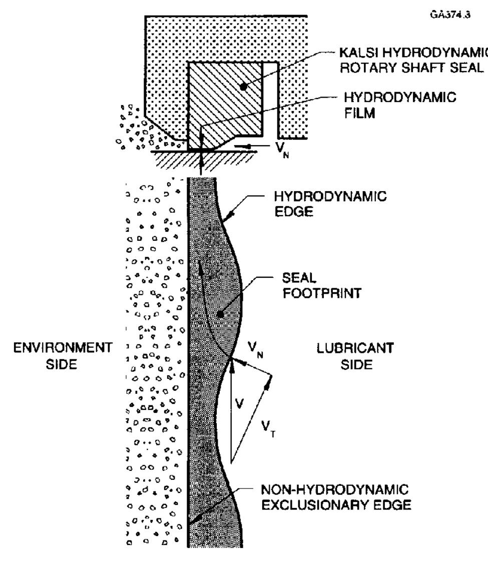
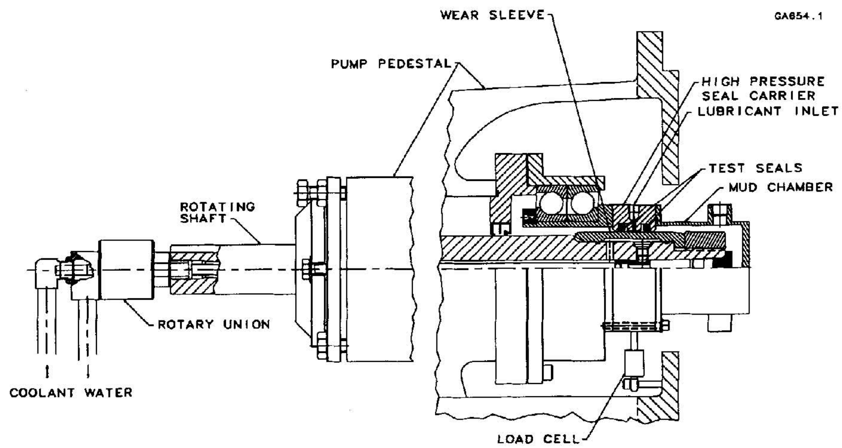


Fig. 1: Principle of the patented Kalsi Hydrodynamic Rotary Shaft Seal Operation

Principle of Operation

The seal is installed with a radial interference in the gland with the same ease as an O-ring and statically performs in the same manner. However, as shown in Fig. 1, the seal's unique geometry creates a wavy hydrodynamic edge on the lubricant side of the seal footprint which, during rotation of the shaft, develops a relative velocity component (V_n) that wedges a film of lubricant at the shaft-to-seal interface causing the seal to hydrodynamically lift and ride on the film. During rotation, the direct contact between the seal and shaft is eliminated, the friction coefficients are very low (typical hydrodynamic range), heat generation is minimized, and wear of both seal and shaft surfaces is virtually eliminated. The sharp edge of the seal on the environmental side is designed to exclude environmental abrasives from entering the seal interface.



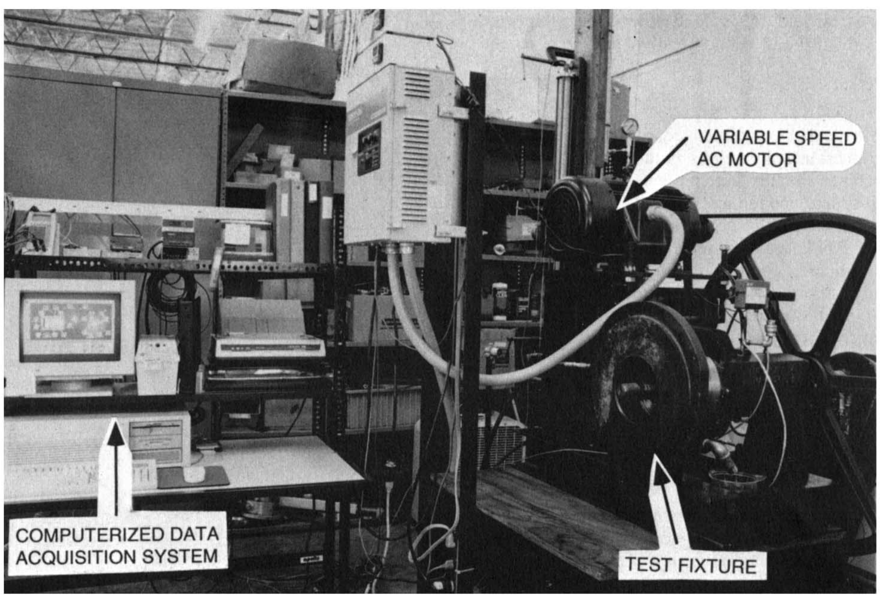


Fig. 2: Seal Test Fixture and Overall Test Setup

Development History

The theoretical and experimental research aspects of the basic seal development included elastohydrodynamic theory of film thickness generation and optical interferometric studies to observe and measure the magnitude of the film thickness over a range of pressures and speeds. These and other development aspects of the hydrodynamic seal, including its implementation in rock bits, are covered in detail in Refs. 1 through 4. After the seal was introduced in the downhole drilling motor application, our organization won a Small Business Innovation Research (SBIR) award from the U.S. Department of Energy (DOE) to further refine and develop the seal design and the implementation hardware for downhole mud motor sealed bearing assemblies and to demonstrate their reliability, consistency, and life by field testing.

A systematic matrix of tests (over 10,000 hours) was run using several special seal test fixtures in our laboratory. **Fig. 2** show the cross-section and overall layout of a typical test setup used to perform parametric tests and long-term life tests.

Parametric tests covered the range of variations encountered in downhole drilling motor environment and seal design, e.g., pressure, speed, temperature, abrasives, shaft runout, seal material, shaft material, and hard surface coatings (Ref. 5). The development effort to handle high pressures, low pressures, zero mean pressure with potential for reversal, and large shaft deflections due to high bit side loads, provided insight into prolonging the seal life in this harsh environment and resulted in a number of patented improvements including a twist-resistant hydrodynamic seal geometry and an articulating/floating seal carrier (Refs. 6, 7). Detailed guidelines for the proper implementation of the seal to consistently achieve long life and avoid common pitfalls are documented in *Using Kalsi Seals® in Downhole Drilling Mud Motor Sealed Bearing Assemblies* available to all users (Ref. 8).

Another SBIR award from DOE, *Development of a Higher Pressure Rotary Blowout Preventer for Safe Directional Drilling in Underbalanced Applications*, allowed our company to develop new seal designs and implementation technology to handle pressures of 5,000 psi and higher (Ref. 9).

In addition to the DOE-sponsored development effort, extensive design, analysis, and laboratory testing has been performed to evaluate application-specific implementations of the seal for different drilling and production equipment. This included evaluation of alternative seal and shaft materials/coatings, thermal analysis to predict under-lip seal temperatures for different applications, and extending the tests to cover downhole temperatures of 300°F and higher.

The seal has been in commercial use in several of these drilling and production applications for a number of years, whereas some applications have only recently been field tested. The details of these applications and field performance are presented in the following sections.

Field Performance

Downhole Drilling Motors. Fig. 3 shows a typical sealed bearing assembly for a downhole mud motor. As shown in Fig. 3, there are two locations for the rotary shaft seal in this application that are critical to the reliability of the tool; each of the locations has its own unique challenge. The lubricant pressure in the sealed bearing chamber is equalized to the downhole pressure in the drill pipe by the use of a floating piston or a compensating diaphragm assembly. On the inner periphery of this piston is a rotary shaft seal that has zero mean differential pressure across it; however, the friction of the seals in the piston and changes in the downhole pressures and temperatures cause a differential pressure to exist across the seal. This differential may be either positive or negative between the mud side and the lubricant side. Even though the severity of this application from a PxV standpoint is low, the reversal of pressure can cause problems in the operation of rotary shaft seals at this location. The lower seal is subjected to the severe combination of high differential pressure, speed, and shaft motion due to bit side loads. Lack of reliability and short life of conventional rotary shaft seals at both of these locations had previously limited the performance, use, and acceptance of sealed bearing assemblies in general.

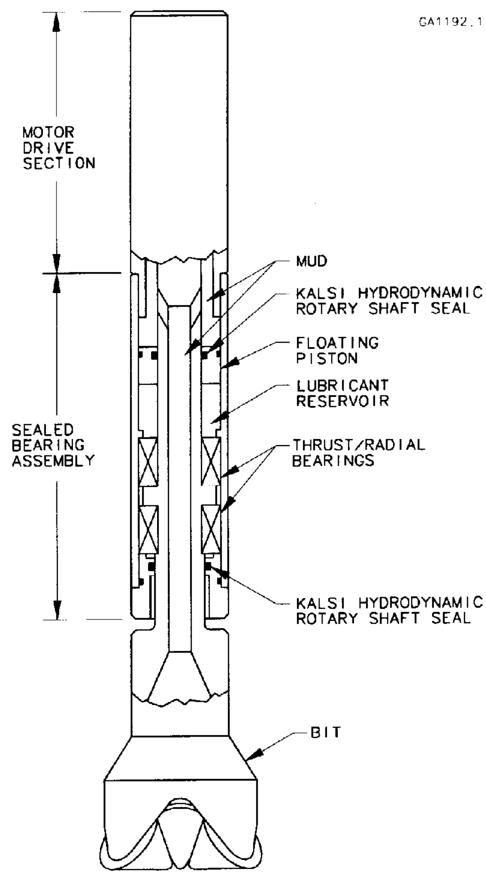


Fig. 3: Schematic of a Typical Sealed Bearing Assembly for a Downhole Mud Motor

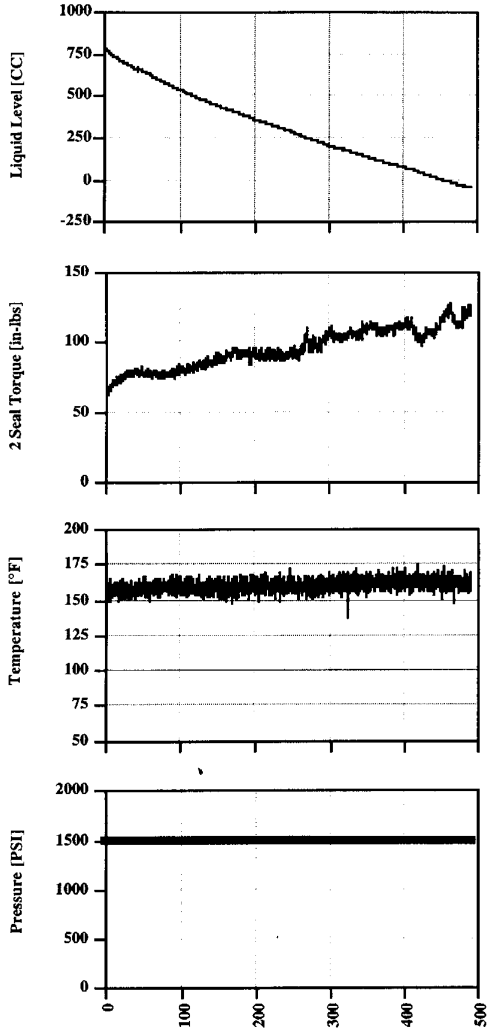


Fig. 4: Results of a Typical 500-Hour Test Under Simulated Downhole Drilling Motor Conditions with 1500 psi ΔP

The systematic development of sealed bearing assemblies under the DOE SBIR sponsored program clearly demonstrated that the novel hydrodynamic seals can perform reliably and consistently met the 500-hour goal under laboratory tests simulating severe downhole conditions (Ref. 5). Over 10,000 hours of testing was performed to understand the effect of the design variables and downhole conditions. Typical results of a 500-hour test performed with a 2.75-inch diameter seal are shown in **Fig. 4**. Both the seal and the shaft surfaces showed little wear after 500 hours of testing. In addition to the laboratory testing, a field test program was conducted to confirm seal performance.

Based upon the successful conclusion of laboratory and field testing, the hydrodynamic seal was put into commercial use. The novel hydrodynamically lubricated seal has eliminated problems that had limited the widespread use of sealed bearing assemblies. Currently the seal is in use by a number of downhole mud motor companies in various hardware implementations. The reliability, consistency, ease of maintenance, and economics of the seal when properly implemented has been proven in over 2,000 motors in use today. Runs of 250 hours are commonplace and runs up to 450 hours have been reported by a number of users. Best performance under differential pressures up to 2,000 psi is achieved when the patented (Ref. 7) articulating or floating seal carrier (**Fig. 5**) is employed. The articulating seal carrier eliminates the net axial force due to pressure differential across the carrier by virtue of the rotating seal interface diameter, D_1, and the static seal diameter, D_2, being equal. This permits the seal carrier to easily follow the shaft motion while maintaining a constant and small extrusion gap and eliminating potential for metal-to-metal contact. The articulating seal carrier can successfully

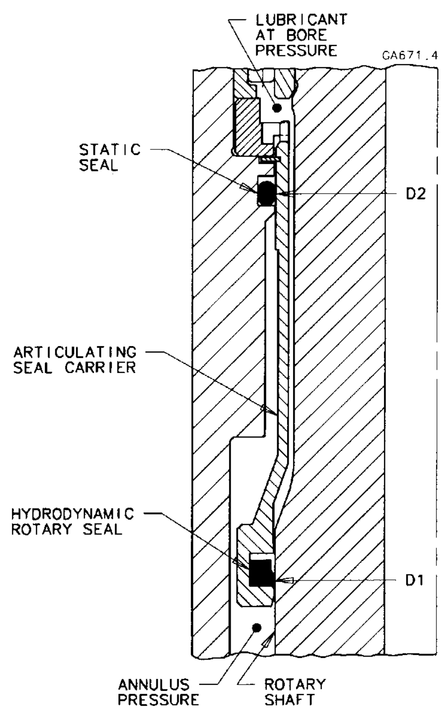


Fig. 5: Articulating Seal Carrier Design (Patented) to Accommodate Large Shaft Motions Due to Bit Side Loads in Downhole Mud Motors

accommodate the large shaft deflections due to high bit side loads which, as discussed in a recent SPE publication (Ref. 10), can be significantly higher than previously believed. Rotary shaft seals exposed to low, zero, or reversing differential pressure encountered in the equalizing pistons can "snake", i.e., acquire a varying axial location in the gland. This can cause abrasive impingement wear on the environmental side of the seal. It was found that the seal should be spring energized, e.g., by wave springs as shown in **Fig. 6**, to combat this problem and reliably achieve long life.

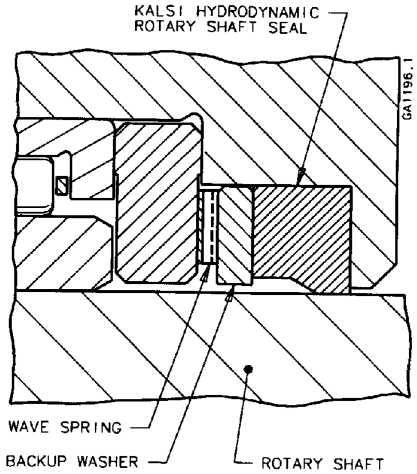


Fig. 6: Hydrodynamic Seal Energized by a Wave Spring to Prevent Seal Snaking in the Groove under Low Pressure Conditions

High Pressure Rotary Blowout Preventers. Fig. 7 shows the high pressure rotary shaft seal locations which had become the limiting component for this equipment used in underbalanced drilling. Five years ago the Kalsi hydrodynamic seal design and the patented laterally floating seal carrier (**Fig. 8**) were introduced into high pressure rotary blowout preventers, which extended the RBOP performance from approximately 500 psi up to 2,500 psi while rotating. The laterally floating seal carrier that is implemented eliminates the axial force across it due to the differential pressure by making the rotary shaft seal interface diameter, D_1, the same as the static seal diameter, D_2. Having no net axial force, the frictional resistance to radial motion of the seal carrier is negligible. The seal carrier bushing, operating in a clean lubricant environment, causes the carrier to easily follow the large shaft runout encountered in this application. Currently three manufacturers are using the hydrodynamic seal in high pressure rotary blowout preventer applications worldwide.

The pressures encountered in underbalanced drilling have continued to increase in recent years (Ref. 11). Under the DOE SBIR sponsored program, the development effort and laboratory tests on the new seal geometry successfully extended the hydrodynamic principle to handle 5,000 psi across the seal at speeds of 200 to 700 ft/min expected in this application while providing very low friction coefficients in the range of 0.015 to 0.02 (**Fig. 9**). The 250-hour goal with 5,000 psi across the seal was met with the seal showing excellent stability, low coefficient of friction, and no degradation at the sealing interface (**Figs. 10 and 11**). The new high pressure seal design and implementation refinements developed under U.S. DOE which have the capability to handle higher pressures are being commercially introduced.

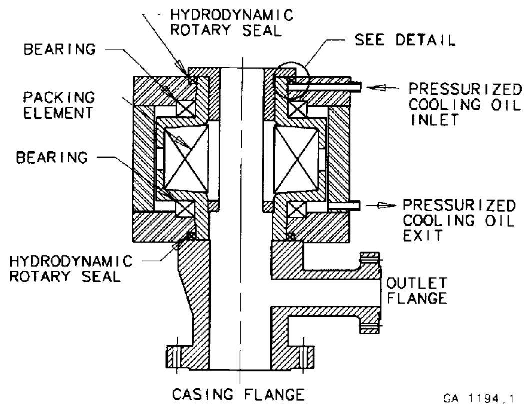


Fig. 7: Schematic of a High Pressure Rotary Blowout Preventer Showing Rotary Shaft Seal Locations

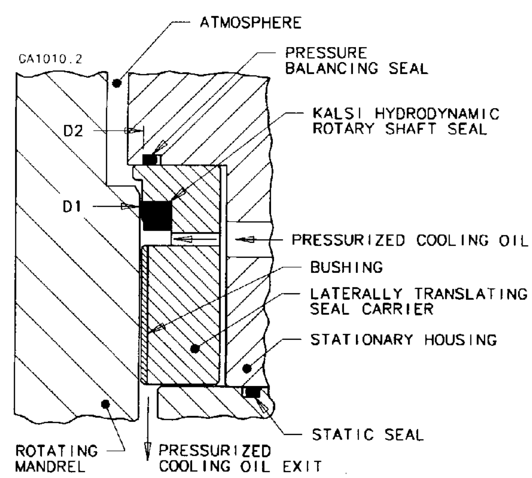


Fig. 8: Laterally Floating Seal Carrier (Patented) Used in High Pressure Rotary Blowout Preventer Applications to Accommodate Large Radial Motions

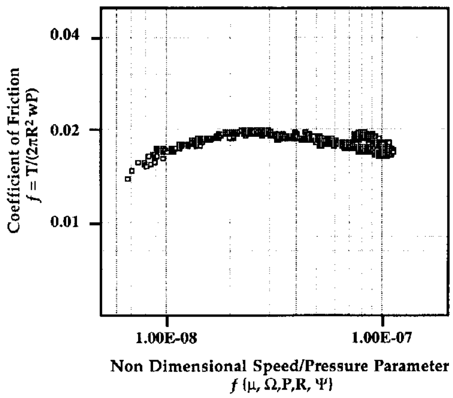


Fig. 9: Low Friction Coefficients Exhibited by the New Hydrodynamic Seal at 5,000 psi and Speeds Up to 700 ft/min

High Pressure, High Speed Swivels (Washpipe Assemblies). High pressure, high speed swivels present another extreme challenge to rotary shaft seals. For example, in high speed coring swivels, the speeds can be as high as 600 to 1,000 rpm with pressures of 3,000 psi. For this severe application, the rig manufacturers have found that none of the conventional seals are able to survive for more than eight hours (e.g., Ref. 12). The hydrodynamic seal was implemented (**Fig. 12**) and has been in successful field use for several years in this application, and seal life of over 1,400 hours was achieved in the first field use. Seal implementation is currently under way for other swivel applications of 7,500 psi and higher.

Progressive Cavity Artificial Lift Pump: Top Drive Stuffing Box. Due to their higher efficiencies and economics, progressive cavity artificial lift pump applications have increased rapidly in recent years (Refs. 13, 14, 15). However, stuffing box leakage is a major source of continuing problems, from the standpoint of both environmental concerns and maintenance cost.

In 1995 a systematic development of the hydrodynamic seal cartridge for this application was initiated by our company. A matrix of short-term and long-term (up to six months) tests was performed to cover the range of speeds (125 to 600 rpm), pressures (60 to 700 psi), fluids, and temperatures (up to 180°F) in this application. After six months of successful laboratory performance, a number of field tests were started in Texas where stuffing box leakage had been a problem. **Figs. 13 and 14** show the implementation of the seal cartridge in the top drive assembly. The seals have performed reliably, with the longest test having accumulated more than seven months of service and still performing well. **Fig. 15** shows the results of the key parameters that are being monitored in this field test. Based on successful laboratory and field testing, the seal cartridge is now being introduced commercially.

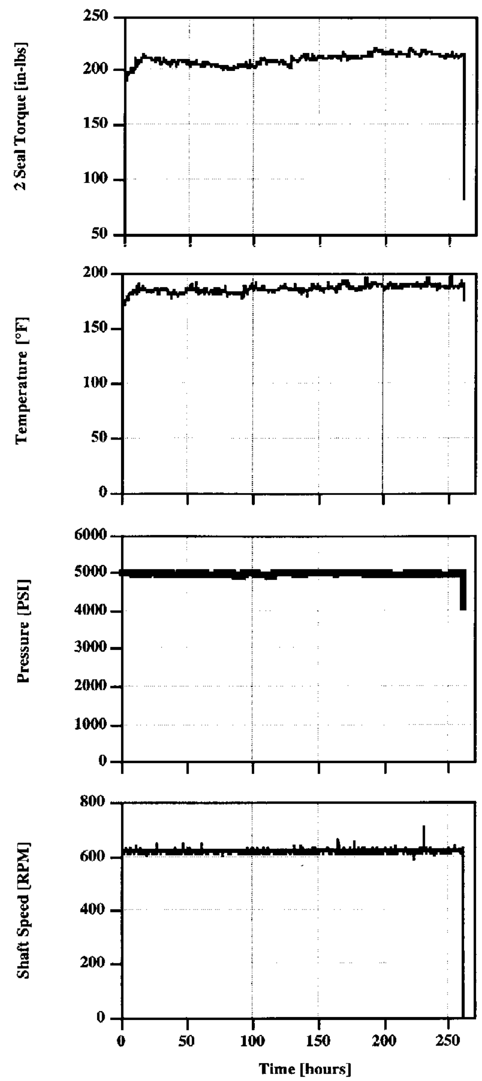


Fig.10: The 250-Hour Test Performance Results from the New Hydrodynamic Seal Design with 5,000 psi ΔP

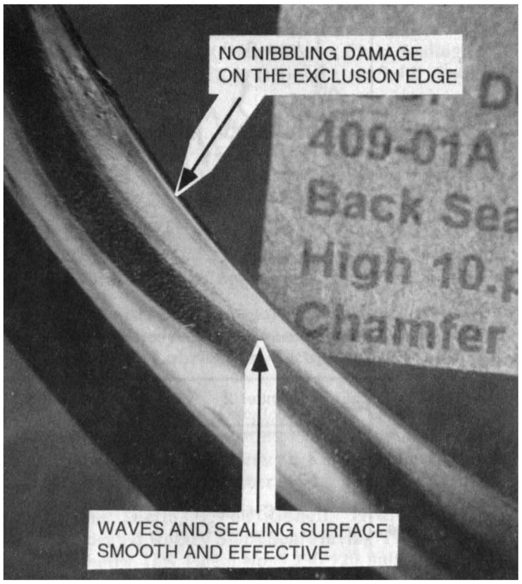


Fig. 11: Excellent Condition of the Seal Interface of the New Seal at the Conclusion of 250-Hour Test with 5,000 psi ΔP

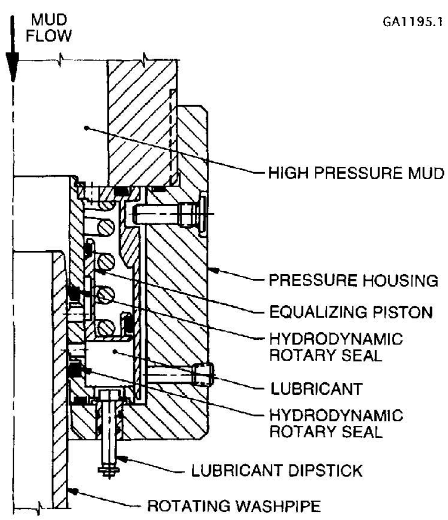


Fig.12: A Hydrodynamic Seal Implementation for High Pressure, High Speed Swivel

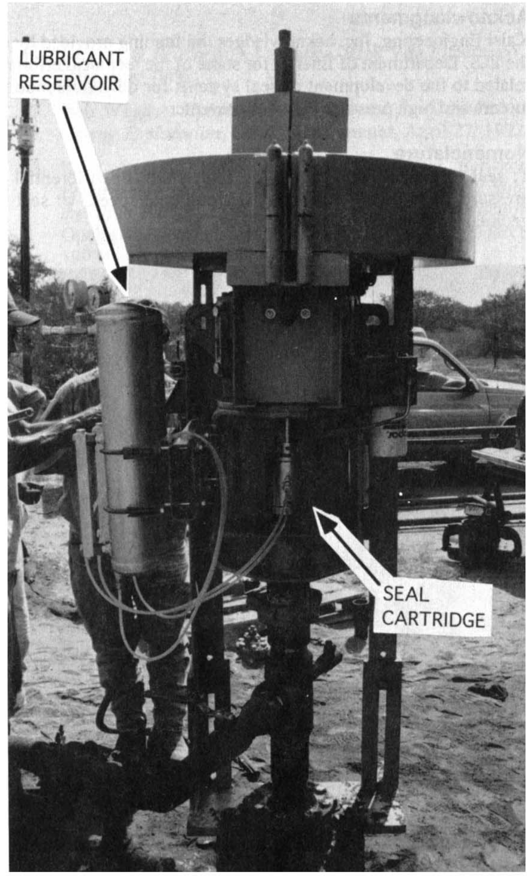


Fig. 13: Progressing Cavity Artificial Lift Pump Top Drive with Kalsi Seal Cartridge

New Generation of Advanced Rotary Steerable Systems. Different advanced rotary steerable systems are currently being developed by a number of companies (Refs. 16 through 19). The rotary shaft seal is a critical element in all of these different systems. The hydrodynamically lubricated rotary shaft seal has been implemented on several of these systems and it has been able to provide satisfactory performance, enabling the development of these advanced tools to progress.

Conclusion

The hydrodynamic seal and the related innovations, when implemented with appropriate consideration for the application constraints, has provided a reliable solution to some of the most severe rotary shaft sealing requirements encountered in drilling and production equipment. This has permitted the state-of-the-art to progress in petroleum equipment.

Acknowledgments

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Nomenclature

T: seal torque, R: seal radius, w: seal width, P: differential pressure, μ: lubricant viscosity, Ω: rotational speed, ψ: seal geometry-dependent parameter.

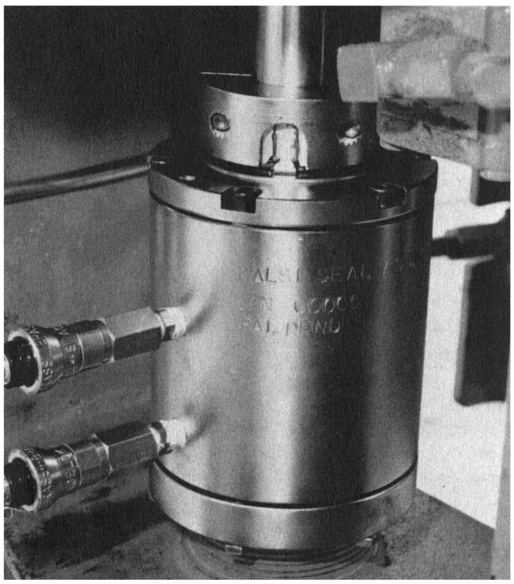

Fig. 14: Seal Cartridge (Patent Pending) for Progressing Cavity Artificial Lift Pump Top Drive

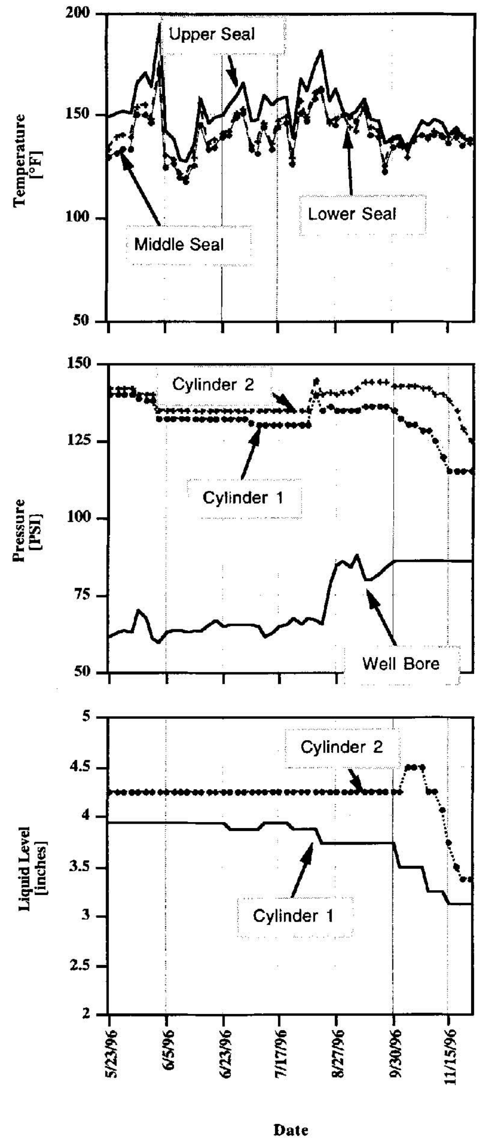

Fig. 15: Field Performance Results from an Artificial Lift Pump Seal Cartridge

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