Ash Handling, Disposal, and Ash Pile Remediation at Romanian Coal-fired Power Plants

Prepared for the

Romanian Energy and Electricity Authority (RENEL)

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Introduction

This topical report has been prepared by the Bechtel Corporation to summarize the results of studies for the Romanian National Electric Authority (RENEL), conducted under contract with the United States Agency for International Development (USAID). The overall objective for the USAID support of RENEL is to improve the efficiency of the Romanian power generating sector. In response to specific requests by RENEL, studies were conducted in the following technical areas:

1. Heavy fuel oil combustion and gas-side corrosion
2. Boiler feedwater treatment and water quality control
3. Ash handling in coal-fired power plants, soils reclamation at full ash storage piles

Study results in each of these technical areas are presented in separate topical reports. This report contains the findings related to Study Area 3.

The specific objectives of Study Area 3 were to:

- Review the existing ash handling systems in RENEL's coal-burning power plants and to suggest potential methods to upgrade these systems
- Review ash handling and storage practices in modern Western power plants and suggest alternative ash disposal options for Romanian coal-fired power plants
- Discuss methods for soil reclamation and remediation in already filled ash disposal sites.

1.1 BACKGROUND

Nearly 60 percent of RENEL's thermal power plants are fueled with coal. The Romanian domestic coal resources consist of low grade brown coal or lignite, containing high percentages of ash and moisture. There are as much as 15 million tons of ash produced annually in the coal-fired power plants.

Typically, the ash collected from various points in the flue gas path is pumped in slurry form to above grade disposal sites near the power plants. Ash handling and disposal consume significant power. The ash/water weight ratio in the slurry is 1:10. Little, if any of the water is recovered. Consequently, the plants require large quantities of makeup water. The ash piles have no means for collecting the conveying water, nor for isolation from the groundwater table. Any chemicals leached out of the ash are carried to the soil and the subsurface water table, causing undesirable pollution of the water supply.

Another issue facing RENEL is that the currently available disposal sites are expected to be full in about 5 years. While there is adequate land nearby for future disposal sites, the land owners are reluctant to sell the land or exchange it for restored former ash piles.

Ash usage for other industrial purposes absorbs only about 1 percent of the ash generated in the coal plants.

RENEL has also identified several operational problems that it has encountered in its present systems. These types of problems have led RENEL to request assistance from the USAID to accumulate data on the following:

- Modern Western ash handling and disposal practices
- Operating experience with ash disposal systems
- Environmental remediation of abandoned ash storage piles

Information in support of the Bechtel effort was provided by RENEL's staff in the course of meetings in the home office and visits to three different power plants. Issues related to ash handling and disposal were covered during the visit to the Craiova II plant in southwestern Romania.

1.2 REPORT ORGANIZATION

The report on ash handling and disposal consists of 5 sections. In addition to this introductory section, this report contains the following:

- Section 2 summarizes the study findings, and presents the conclusions and recommendations derived from the study
- Section 3 describes the features and operation of the ash handling and disposal systems in representative Romanian coal-fired power plants
- Section 4 contains information regarding Western ash disposal systems and methods for soil remediation at ash piles that have reached their storage capacity. Potential uses of the ash in commercial and industrial applications are also discussed in this section
- Section 5 describes recent Western operating experience with ash handling and disposal methods.

Section 2

Summary, Conclusions, and Recommendations

Coal-fired power plants represent about 58 percent of RENEL thermal power generating capacity. Since these plants use fuel from domestic sources, they are of major importance to the Romanian economy. A large percentage of the coal-fired plants use lignite as fuel. The heating value of the lignite is 1,200 and 1,700 kcal/kg. The ash content is about 29 percent. The relatively low heating values and high ash content result in an annual ash production of 10 to 15 million tons in the Romanian power plants. On an equal heat input basis, the ash production is as much as 7 times higher than that produced in a bituminous coal-fired plant.

The ash from the power plants is almost exclusively removed by means of slurry pumping to ash piles near the plants. RENEL is experiencing some problems with its current ash handling method, and they have been identified as follows:

- The demand for ash supply and pumping power is excessive.
- Ash piles occupy large land area and the supply of suitable land is rapidly diminishing.
- The slurry pumps have poor reliability.
- The steel pipes used to transport the ash slurry to the ash piles are prone to clogging, deposit buildup and corrosion/erosion damage.
- The current ash piles are environmentally harmful. Chemicals leaching from the ash contaminate the groundwater supply. Windblown dust contaminates the air.

Although several power plants are equipped with provisions for dry collection of ash for sale to industry, these provisions are rudimentary and have only limited capacity.

Recognizing the urgent need to find solutions to the above problems, RENEL has requested assistance from the U.S. AID. The study task, covered in this topical report and performed by Bechtel Corporation, was conducted in response to this request. The task represents the initial step of identifying the following:

- Modern Western methods for efficient in-plant ash handling and disposal methods
- Commercial and industrial uses for the ash
- Potential means for reclaiming the land occupied by the current ash piles after reaching their storage capacity
- Methods for environmentally benign storage methods for ash disposal

Based on the above information, promising methods for solving the ash handling and disposal problems are to be recommended for further evaluations.

2.1 ASH DISPOSAL METHODS

The most desirable and environmentally least harmful way to dispose of power plant ash is to recycle it for industrial or commercial use. Compared to the 1 percent used in Romania for such purposes, the United States recycles an average of 25 percent of the ash. (Although some utility companies, which employ aggressive marketing activities, have sold above 70 percent of the ash for industrial uses.) In European countries, where land is scarce, the percentages are even higher. They range from 92 percent in Italy to 35 percent in Great Britain. France uses about 57 percent of the ash.

Any ash that cannot be sold because of poor quality or due to market saturation is transported off site for landfilling or is impounded at the plant site. In the United States, power plant ash is considered as nonhazardous waste, suitable for normal landfilling. However, groundwater monitoring is required at the disposal facilities to confirm that the water quality is not adversely affected. In the United States, about 48 percent of the unused fly ash is collected in temporary storage silos for shipment to landfill sites. Instead of transportation to a landfill site, the ash has been returned to the mine for reinjection into depleted shafts or for use in restoration of strip mine land. This method has been used in Europe and the states.

Final ash disposal at or near the plant site is normally done in ash ponds. In the states, about 52 percent of the ash is sluiced to disposal ponds. Ash piles are not commonly used. The ponds usually have a primary pond and at least one discharge pond. Water collected in the discharge ponds is sent back to the plant for reuse. As much as 90 percent of the water is recycled in some locations. A representative plant in the midwest United States has ponds covering 113 hectares (280 acres) for a 1,000-MW power plant. The pond has been in use for 20 years and has received 10 million cubic meters of fly ash.

Except in heavy clay soils, the ponds are lined with plastic. High-density polyethylene liners have shown the least adverse effects to long-term exposure to coal ash. Groundwater monitoring wells are sunk to the water table to observe any undesirable leaching from the ponds.

Once the ponds of landfill have reached their capacity, they are capped with several feet of dirt. Depending on the soil characteristics and expected precipitation, liners may or may not be used. After capping, the land may be returned for use. There have been sport centers, golf courses, parks and recreational areas established on former pond sites.

Some sites have been revegetated to restore their natural state. Since the ash characteristics vary significantly from coal to another, it is often required to conduct experiments to determine the most suitable vegetation. The experimental farm on the Craiova ash pile is a good example for such efforts.

A major concern with ash ponds is the control of fugitive dust. There are now commercially available materials that can be sprayed on the surfaces to prevent such occurrences.

2.2 INDUSTRIAL AND COMMERCIAL USES FOR ASH

Prompted by ever tightening environmental regulations for ash disposal and increases in the cost of ash disposal, extensive research efforts and aggressive marketing is in progress to broaden the field of commercial use. Table 2-1 summarizes the potential market for coal-fired plant ash. The table also indicates the level of technology involved in a given application.

Largest ash quantities may be used in highway and levee construction. Some 700,000 tonnes of ash was used recently to build a berm behind a levee in the United States. Similar projects have used large quantities of ash in France and England. Because of transportation costs, the economically most attractive applications for unimproved ash are within a 50 km radius of the power plant.

The economics become more attractive if the ash is used to manufacture portland cement, precast concrete panels, or building blocks for the construction industry. Such manufacturing plants should be built near the power plants. They do require some capital investments. However, because of the added value, greater transportation distances become feasible.

Current research is attempting to use ash as filler material for metal composites, such as aluminum graphite and aluminum silicon carbide. Cast aluminum-fly ash composites are under development at the University of Wisconsin.

As mentioned earlier, wide usage of the ash can be promoted by aggressive marketing efforts. In the United States, the American Coal Ash Association (ACAA) has been promoting coal ash use and has represented the ash producers and marketers since 1968.

Table 2-1
Potential Uses of Wastes from Pulverized Coal Firing

Utilization Markets	Conventional Materials	By-Product Type[a]	Potential By-Product Volume	Technology Requirements	Market Value	Major Advantage	Major Disadvantage	Utilization Outlook
Cement	Cement	BA, FA	Moderate	Moderate	High	Cost savings	Quality control	Good
Concrete and construction materials	Sand, gravel, and stone	BA, FA	Moderate	Moderate	Low	Cost savings	Quality control	Good
Bituminous pavements	Sand and gravel, stone	BA, FA	High	Low	Low	Processing economics	Product acceptability	Moderate
Structural fill/fill materials	Soil, stone, sand, and gravel	BA, FA	High	Low	Low	Urban and industrial proximity	Product acceptability	Good
Soil stabilization	Lime, cement	FA	Low	Moderate	High	Cost savings	–	Moderate
Deicer/anti-skid	Salt, sand, and gravel	BA	Moderate-high	Low	Low-moderate	Non-corrosive	–	Good
Roofing granules	Stone, sand, and gravel	BA	Moderate	Moderate	Low	–	–	Good
Grouting	Cement	FA	Low-moderate	Moderate	High	Cost savings	Ash quality	Good
Mineral wood	Furnace slag, wool rock	FA	Low	Moderate	Moderate	Market proximity	Atypical furnace	Moderate
Agriculture	Ag-lime fertilizers	FA, FGD	High	Low	Low	–	Replacement ratio	Poor-moderate
Metals recovery[b]	Natural ores	FA	High	High	High	–	Costs, residue volume	Low
Sulfur recovery	Natural sulfur	FGD	High	High	Moderate	–	Costs	Low
Gypsum	Natural gypsum	FGD	High	Moderate	Moderate	–	Product acceptability	Low

(a) BA = bottom ash; FA = fly ash; FGD = flue gas desulfurization sludge.
(b) Includes aluminum, titanium, iron, and silica.
Adapted from *Coal Combustion By-Products Utilization Manual*, Vol. 1: *Evaluating the Utilization Option*, Table 4-1, EPRI CS-3122, Electric Power Research Institute, Palo Alto, California, February 1984.

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2.3 IN-PLANT ASH HANDLING PRACTICES

Coal-based solid wastes in power plants are collected at four locations:

- Coarse bottom ash under the furnace
- Pulverizer rejects at the pulverizing mills
- Intermediate particle size ash below the economizer section
- Fine particle size fly ash below the electrostatic precipitators

Because of the differing quantities and ash conditions, there are variations in the collection methods at these locations.

2.3.1 Bottom Ash

Bottom ash was historically collected in water impounded hoppers with hydraulic transportation. The system was usually designed for intermittent operation, particularly in plants burning low ash coals. Starting in the 1980s, the so-called submerged chain conveyors (SCC) came into use, particularly in Europe. These conveyors are designed for continuous operation which is desirable with higher ash coals. Because of the lower profile, these designs helped to save plant costs due to lower building heights. Initially, the SCC used water for cooling of the ash. The water was drained from the ash, cooled, and returned to the conveyor.

In a more recent development, the water was replaced with air cooling. In addition to lower water consumption, this design improved the plant thermal efficiency, since the air helped to combust the residual carbon and the hot air was introduced into the furnace. Regardless of the cooling method, the SCC allowed dry handling of the ash.

Operating experience with these conveyors brought about improvements in the configuration and changes to more durable materials for the chains.

2.3.2 Pulverizer Rejects

Pulverizer rejects are collected at the bottom of the pulverizer mills. From here, they are usually sluiced to a convenient part of the ash collecting system. In older plants, the reject was sequentially sluiced to the bottom ash hopper from each mill. In newer plants, particularly those using the SCC, each mill is equipped with a jet pump to transport the rejects to a point outside the furnace. Either hydraulic or pneumatic conveyance may be used.

2.3.3 Economizer Ash

Economizer ash is collected in hoppers beneath the economizer section of the boiler. Low calcium ash can be collected in water-impounded hoppers. However, with subbituminous coals and lignite, which usually contain more calcium, such practice could lead to plugging of the hoppers with concrete. This situation, in turn, could lead to air preheater plugging since the economizer ash is carried on by the flue gas. Adequate design of the evacuation system is essential to troublef-ree operation.

2.3.4 Fly Ash System

The fly ash system handles the largest fraction of the total ash. The conventional practice in the United States is to collect the fly ash in hoppers beneath the precipitators. From there, the ash is removed intermittently. There are several pneumatic and hydraulic transport system designs in use. Because of the sensitivity to malfunctions of the collection and transportation system, the American Boiler Manufacturers Association (ABMA) has published guidelines for the design and operation of such systems. An interesting design, aimed at preventing ash compaction in the hoppers, introduces an air-blown fluidizer at the hopper outlet. The currently preferred design uses vacuum transport of the ash to a nearby temporary storage silo.

2.4 TRANSPORT TO IMPOUNDMENT

In the United States, the current practice is to transport the ash in slurry form to the impoundment. Water-to-ash weight ratios are as low as 6:1. The slurry velocities in the pipes are seldom higher than 2.7 m/sec (9 ft/sec). In a recent design, used in the water-poor southwestern United States, a system with water-to-ash ratio of 1:1 was specified. In this case, the usual centrifugal pumps were replaced with positive displacement pumps. The advantages cited were lower water use, lower pumping power, and less wear in the pipes. The reduced wear is the result of lower flow velocities.

To reduce wear problem in the slurry pipes and to prolong service life, in recent years, heavy wall carbon steel piping and piping made of abrasion-resistant materials have been specified. Such materials include heat-treated alloy steel, case-hardened steel, solid basalt, or basalt-lined pipes. In one United States power plant, the pipes are made of ceramic lined, fiberglass reinforced epoxy. This material has a life expectancy of 17 years. Urethane-lined steel pipes had successful use with ash systems. These pipes are, however, quite costly.

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2.5 CONCLUSIONS AND RECOMMENDATIONS

This report presents an overview of modern Western practices for ash handling, transportation, and final disposal. There are a number of improvements in these areas that could benefit RENEL's system. However, specific recommendations are not appropriate at this time, because the conditions and the coal characteristics have major impact on the selection of the most appropriate design choices.

The next logical step will be to conduct site-specific evaluations. Such evaluations should define the technically and economically preferred solutions to the local problems. Considering that plant improvement projects require several years from completion of these studies, it is recommended that the projects be prioritized according to the urgency of completion. This is particularly applicable to finding acceptable solutions to the shortage of ash storage capacity.

Section 3

Current Ash Handling and Disposal Provisions in Romanian Power Plants

Data provided by RENEL lists 22 coal-fired power plants. The total generating capacity is about 10,200 MW. Coal-fired power plants are located in the mountainous regions in the north, in the plains along the Danube River, the coastal areas along the Black Sea, and on gently rolling regions in the southwestern part adjacent to local rivers. Ash storage information was provided for the six most important plants, representing a generating capacity of about 7,700 MW. Site-specific information was gathered during the plant visit at Craiova II.

There are coal resources in various regions of the country. Strip mining is the most frequent recovery method with some underground mining. Rail and truck transportation is used to deliver the coal to the power plants. Most of the plants burn low heating value indigenous brown coal. The coal used in Craiova, for example, has about 29 percent ash and around 41 percent moisture. The higher heating value is 1,200 to 1,700 kcal/kg (2,200 to 3,100 Btu/lb). On an equal heat input basis, this coal produces 7 times more ash than a medium quality bituminous U.S. coal (Illinois No 6).

Table 3-1 lists the ash test results at the Craiova plant. The ash particle size consist typical for six Romanian coal-fired plants is shown in Table 3-2.

3.1 ASH DISPOSAL PROVISIONS

Depending on demand for electricity, the Romanian coal-fired plants generate 10 to 15 million tons of ash annually. Only about 1 percent of this quantity is sold for industrial use. The remainder is stored in above ground ash piles near the plants. Ash storage areas for the six most important power plants are listed in Table 3-3. It has been reported that the ash pile at the Craiova II plant will be filled in about 5 years. There is an apparent resistance by owners of the surrounding land to sell or trade their properties to be used for additional ash storage space.

The ash piles are surrounded with a 3 to 6 m (10 to 20 ft) high earthen berm to confine the deposited ash. As the ash height reaches the top of the berm, a new berm is constructed slightly inboard from the one below. The outside surface of the berm has a 3:1 slope. As evident from Table 3-3, ash piles are allowed to reach heights above 40m (130 ft). There is no water recovery provision at the ash piles. The transport and rain water are allowed to percolate into the soil beneath the pile. At Craiova, the outer surface of the berm had only spotty natural vegetation; no grass mat to prevent washout was evident.

Table 3-1
Ash Test Results for Type B Fuel
Craiova I Power Plant, Romania

Denomination	Symbol	U.M.	STAS* Limiting Value	Measured Values			
				Minimum	Date	Maximum	Date
Wetness	W	%	Max. 1	0.05	April 1989	0.5	Oct. 1989
Retained on 0.2 mm sieve size	RO_2	%	Max. 10	1.4	April 1990	11.8	Mar. 1990
Calcination loss	PC	%	Max. 3	0.6	Oct. 1989	1.4	Jan. 1989
Activity number	Fzv	%	Min. 75	77.3	May 1989	83.0	Aug. 1989
Silicon dioxide	SiO_2	%	Min. 49	41.9	Nov. 1989	46.8	May 1989
Magnesium oxide	MgO	%	Max. 4	2.0	Jan. 1989	4.0	Mar. 1989
Calcium oxide	CaO	%	Min. 7	6.7	Jan. 1989	10.7	Nov. 1989
Iron trioxide	Fe_2O_2	%	Min. 9	8.9	April 1990	18.7	May 1989
Aluminum oxide	Al_2O_3	%	Min. 20	18.8	May 1989	25.2	April 1989
Sulphur trioxide	SO_3	%	Max. 2	1.0	Jan. 1989	3.1	Nov. 1989

* STAS = Romanian Standard

NOTES:

1) Fusion Temperature: 1120°C
2) Melt Temperature: 1150°C
3) Flow Temperature: 1185C

Reference: Provided by a member of the CRAIOVA I Power Plant, July 21, 1993.

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Table 3-2
Typical Range of Size Distribution for Ash
RENEL, Romania

Grain Diameter (mm)		% By Weight
Maximum	Minimum	
2	0.5	2 to 8
0.5	0.25	6 to 16
0.25	0.05	26 to 44
0.05	0.005	32 to 50
0.005	0.0002	4 to 16

Typical for six power plants in Romania.

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Table 3-3
Ash Storage Areas in Main Power Plants

Plant and Storage Area Name	Land Area (hectares/acres)	Height (m/ft)	Remarks
TURCENI T.P.P.			
Valea Ceplea	161.7 / 400	0.0 / 0	To be reused
Storage #2	169.0 / 420	8.5 / 28	In operation
ROVINARI TPP			
Cicani West	65.4 / 160	15.0 / 49	90% full
Cicani East	66.0 / 163	17.0 / 56	90% full
Beteregea	118.0 / 290	0.9 / 3	In operation
ISALNITA TPP			
Right-bank storage	145.0 / 360	26.0 / 85	In operation
Left-bank storage	136.0 / 340	32.0 / 105	In operation
MINTIA-DEVA TPP			
Mures right bank	63.0 / 156	40.0 / 130	In operation
Bejan Valley	87.0 / 215	26.0 / 85	In operation
DOICESTI TPP			
Storage #1	12.0 / 30	38.0 / 125	Exhausted
Storage #2	25.0 / 63	42.0 / 138	Exhausted
Storage #3	10.0 / 25	28.0 / 92	To be used
Poiana Mare	48.0 / 120	29.0 / 95	In operation
Storage #5	18.0 / 45	0.0	Under consideration
CRAIOVA II TPP	120.0 / 300	30.0 / 100	In operation

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3.2 ASH COLLECTION AND TRANSPORT TO DISPOSAL

In the power plants, the bottom ash, economizer ash, the flyash from the electrostatic precipitators, and solids collected in dust control cyclones are typically sluiced into a slag and ash basin. From here, the slurry is then pumped through steel pipes to the top of the ash pile. The Bagger pumps used for this purpose have to overcome the friction pressure drop in the pipes (which may be longer than 3 km or 1.5 mi), and the static head of the water column at the discharge point. The in-plant wet ash handling system is shown in Figure 3-1.

In a few instances, where RENEL is able to sell some of the ash, the fly ash from the electrostatic precipitator is collected in a rudimentary dry system of modest capacity. Should the industrial demand for ash increase significantly, the present system would have to be modernized and enlarged. The dry ash handling system is shown in Figure 3-2.

3.3 SHORTCOMINGS OF THE CURRENT SYSTEM

In RENEL's assessment, the current ash handling and disposal systems have major disadvantages:

- At concentrations of 8 to 10 kg water per kg of ash, the wet handling system requires very large amounts of water. Little, if any, of this water is recycled.
- The auxiliary power required to run the pumps is between 5 and 15 kWh/tonne. Using an average power requirement and an average ash production, the annual energy consumption is 1.25*10^8 kWH/year. This represents a significant loss of salable electric power.
- The Bagger pumps used for transporting the slurry to the ash pile have a poor record of reliability.
- The ash piping is prone to clogging with ash deposits. The steel piping used in the transfer lines are suffering severe corrosive/erosive damage, requiring frequent maintenance.
- High-pressure drop in the piping and large static heads often require tandem pumping, which leads to operational problems and cavitation.
- The ash piles occupy large plots of land. Acquisition of additional land is becoming progressively more difficult.

- The ash storage piles are environmentally objectionable. In their present condition, the ash piles are causing soil and groundwater contamination. Fugitive dust from the dry ash pile surfaces is leading to atmospheric contamination.

These problems need urgent attention to remove operational inefficiencies and environmental contamination.

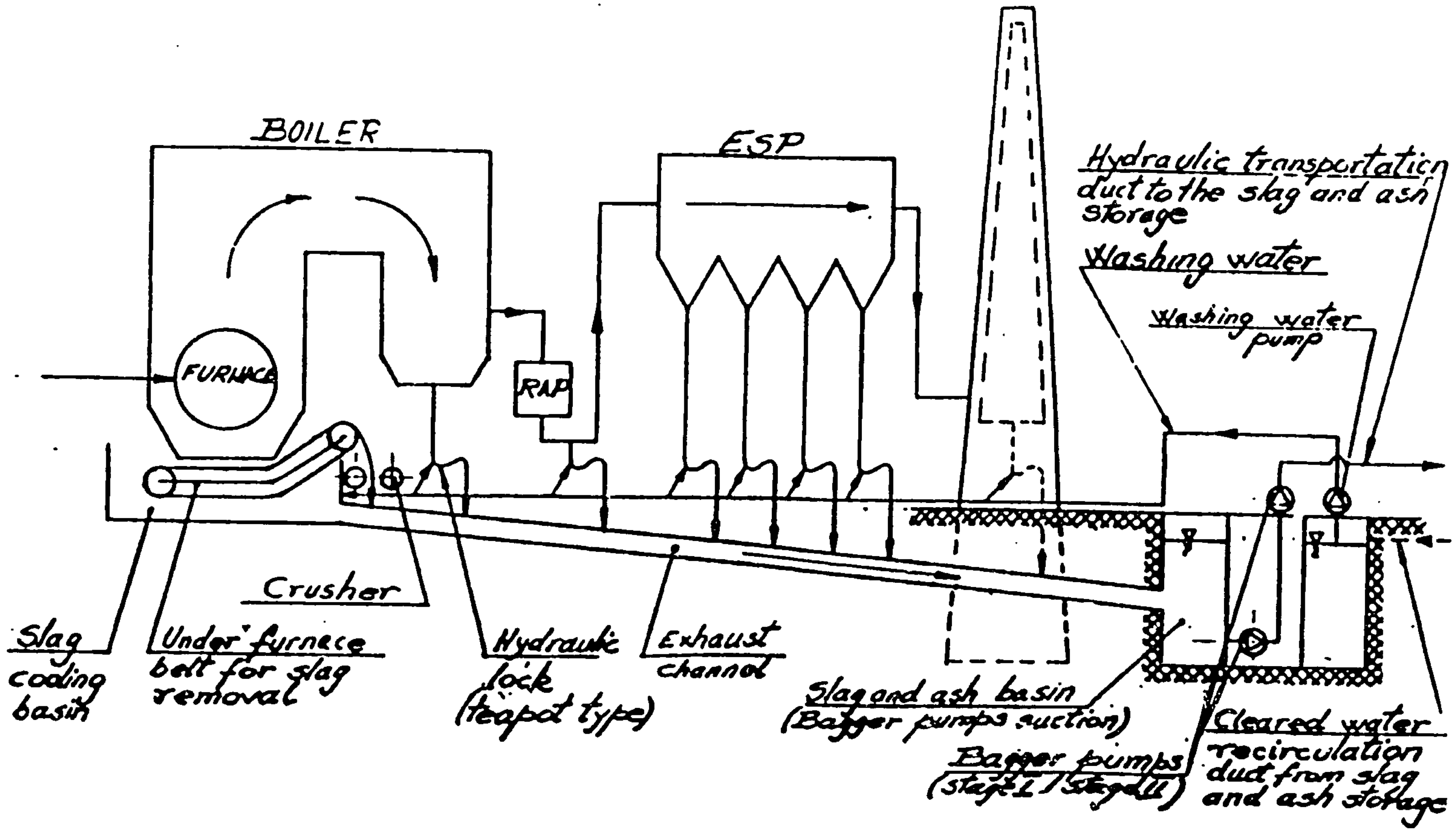

Figure 3-1 RENEL SCC with Hydraulic Transport System

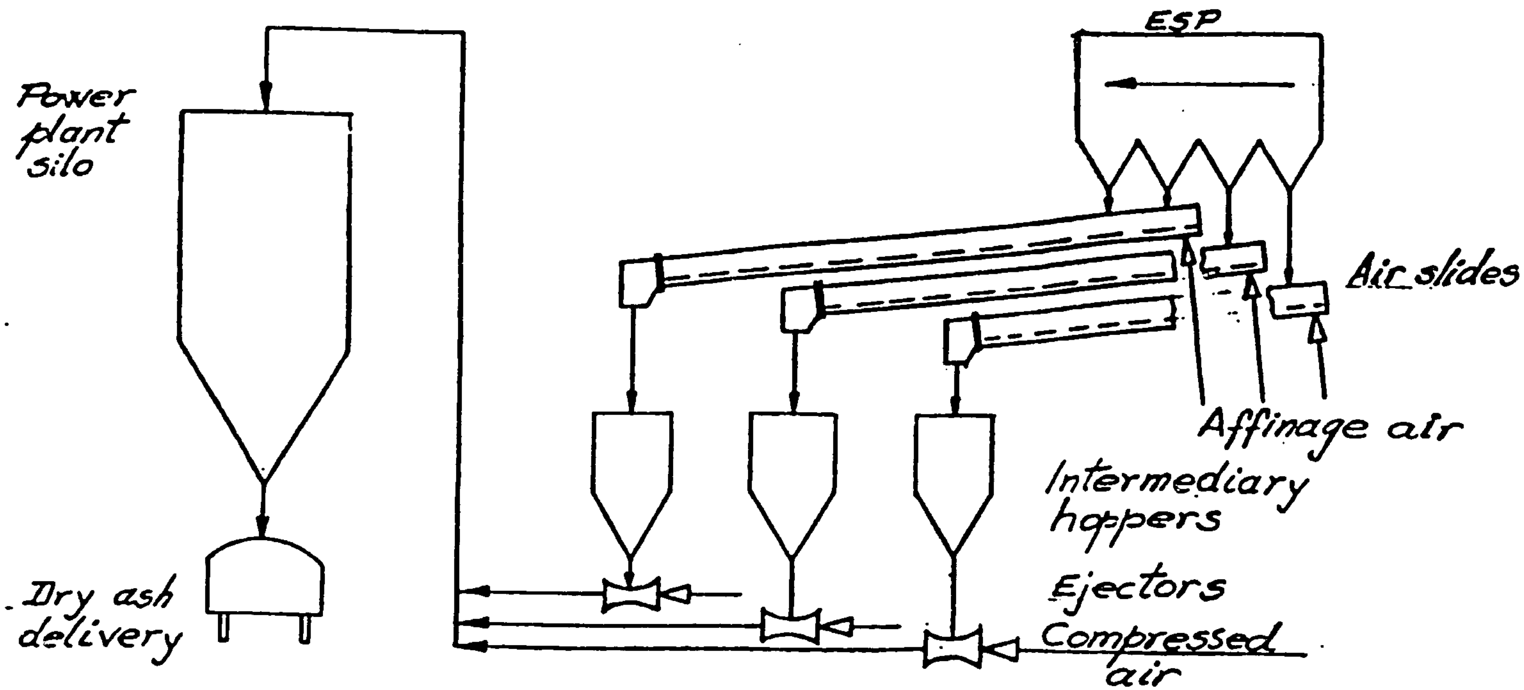

Figure 3-2 RENEL ESP Dry Ash Removal Using Air Slides

Section 4

Ash Disposal and Soil Reclamation

Coal-fired power plants generate large volumes of ash which can tie up large tracts of land for permanent storage. The land use for waste storage may be somewhat reduced by switching to low ash, higher quality coal, and improving the plant heat rates. However, these measures may have only limited benefits. While unused, barren lands may still be available in some regions for permanent ash storage, land near power plants is too valuable to permit unrestricted use for ash storage in most of the civilized world. Shortage of land or problems associated with land acquisition for ash disposal could significantly increase the cost of power generation and jeopardize operation of many power plants. Proper ash disposal practices are essential to prevent wasteful land depletion and to minimize adverse environmental impacts.

Proper ash disposal practices include aggressive marketing to promote industrial use of ash, proper containment of ash for ultimate disposal, efficient management of land use, and economic reclamation of land after the ash disposal facilities are closed.

Current Romanian ash storage practices have been outlined in Section 3 of this report. This section contains descriptions of potential industrial/commercial use of ash, modern methods of ash management (storage, disposal, stabilization, remediation, and reclamation) and methods recommended to improve the current ash management practices in Romania.

4.1 INDUSTRIAL AND COMMERCIAL USES OF ASH

Ash from coal-fired power plants represents the fastest growing waste material in the United States and in other countries that rely on coal as the main source of fuel. In the United States, power plants currently produce 50 to 60 million tons of fly ash. It is expected that this quantity may double by the year 2000. Only about 25 percent of the ash is recycled for industrial use. The remainder is landfilled at an estimated annual cost of $1 billion. The rate of ash utilization in European countries, where land is quite scarce, ranges from 92 percent in Italy to 35 percent in Great Britain. France uses about 57 percent.

Although the U.S. average indicates that about 25 percent of the generated fly ash was marketed in 1990 (Table 4-1), the percentage was considerably higher where aggressive marketing efforts were employed. For example, the Arkansas Power & Light Company (AP&L) has significantly increased the sale of fly ash generated in its White Bluff and Independence power plants. While about 33 percent of the White Bluff coal ash was sold in the 1980s, by the 1990s, White Bluff sold approximately 70 percent of its combined ash products and 95 percent of its fly ash. This increase was largely the result of marketing efforts by the utility company.

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Table 4-1
Solid Wastes from U.S. Coal-Fired Power Plants
(1990 Production and Utilization in millions of U.S. tons)

	Fly Ash	Bottom Ash	Slag	Subtotal Coal Ash	FGD Solids	Total Solid Wastes
Production	**48.9**	**13.7**	**5.23**	**67.83**	**18.9**	**86.73**
External Utilization Markets						
Cement/concrete	7.18	0.5	0.31	7.99	0	7.99
Structural fills	0.43	0.41	0	0.84	0.02	0.86
Roadbase/sub-base	0.78	0.44	0.15	1.37	0	1.37
Asphalt filter	0.13	0.003	0.02	0.153	0	0.153
Snow, ice control	0	0.81	0.89	1.7	0	1.7
Blasting grit	0	0.18	1.66	1.84	0	1.84
Grouting	0.34	0	0	0.34	0	0.34
Mining reclamation	0.06	0	0	0.06	0.04	0.1
Miscellaneous other	0.64	0.37	0.06	1.07	0.09	1.16
Subtotal	**9.56**	**2.71**	**3.09**	**15.36**	**0.15**	**15.51**
Internal Utility Uses						
Cement/concrete	0.006	0	0	0.006	0	0.006
Structural fills	2.25	1.07	0.006	3.326	0.0003	3.326
Roadbase/sub-base	0.06	0.56	0.001	0.621	0.006	0.627
Snow, ice control	0	0.02	0.004	0.024	0	0.024
Miscellaneous other	0.54	1.00	0.15	1.69	0.0.53	1.743
Subtotal	**2.86**	**2.65**	**0.16**	**5.67**	**0.06**	**5.73**
Total utilization	**12.42**	**5.36**	**3.25**	**21.03**	**0.21**	**21.24**
Total utilization as a percentage of production	25.4%	39.1%	62.1%	31.0%	1.1%	24.5%

Source: American Coal Ash Association

Table 4-2 presents a summary of the potential markets for pulverized coal-fired plant wastes. The table also provides data on the level of technology employed in the different usages. Markets for power plant wastes may be divided into the following categories:

- High volume - low technology uses
- Medium technology uses
- High technology uses

4.1.1 High Volume - Low Technology Uses

In addition to the large ash quantities used, the application in construction has the advantage that it requires low technology levels and it is not sensitive to the ash characteristics. Applications that typically require large quantities of ash include:

- Structural fills
- Highway embankments backfills
- Subgrade stabilization for highways and airport runways of real estate developments
- Waste material stabilization
- Soil conditioning for agricultural land

Fly ash, bottom ash, and slag, alone or in mixed form, have been used in the United States and Europe as structural fill material for roads, construction sites, dams, and dikes. In the United Kingdom, ash has been used in highway embankments with particular applications as fill dirt behind bridge embankments. In the United Kingdom and in France, fly ash was used as structural fill to confine fly ash ponds. In the United States, a 6 mile-long berm behind a levy was recently constructed with mixed ash. Approximately 700,000 tonnes of ash, reclaimed from ash ponds, was used. About 10,000 tonnes of ash was used to construct access ramps in the state of Delaware. In the state of Pennsylvania, 350,000 tonnes of ash was used to build a 500-meter-long highway embankment.

"Pozzolanic mixtures," consisting of fly ash, activators, aggregate and water, have been used for years as base layers of asphalted highways.

Controlled low-strength materials (CLSM), consisting of a mixture of fly ash and cement (with up to 90 percent ash), are used for easily removable backfill. The percentage of cement is used as the method to control the strength.

Table 4-2
Potential Uses of Wastes from Pulverized Coal Firing

Utilization Markets	Conventional Materials	By-Product Type[a]	Potential By-Product Volume	Technology Requirements	Market Value	Major Advantage	Major Disadvantage	Utilization Outlook
Cement	Cement	BA, FA	Moderate	Moderate	High	Cost savings	Quality control	Good
Concrete and construction materials	Sand, gravel, and stone	BA, FA	Moderate	Moderate	Low	Cost savings	Quality control	Good
Bituminous pavements	Sand and gravel, stone	BA, FA	High	Low	Low	Processing economics	Product acceptability	Moderate
Structural fill/fill materials	Soil, stone, sand, and gravel	BA, FA	High	Low	Low	Urban and industrial proximity	Product acceptability	Good
Soil stabilization	Lime, cement	FA	Low	Moderate	High	Cost savings	–	Moderate
Deicer/anti-skid	Salt, sand, and gravel	BA	Moderate-high	Low	Low-moderate	Non-corrosive	–	Good
Roofing granules	Stone, sand, and gravel	BA	Moderate	Moderate	Low	–	–	Good
Grouting	Cement	FA	Low-moderate	Moderate	High	Cost savings	Ash quality	Good
Mineral wood	Furnace slag, wool rock	FA	Low	Moderate	Moderate	Market proximity	Atypical furnace	Moderate
Agriculture	Ag-lime fertilizers	FA, FGD	High	Low	Low	–	Replacement ratio	Poor-moderate
Metals recovery[b]	Natural ores	FA	High	High	High	–	Costs, residue volume	Low
Sulfur recovery	Natural sulfur	FGD	High	High	Moderate	–	Costs	Low
Gypsum	Natural gypsum	FGD	High	Moderate	Moderate	–	Product acceptability	Low

(a) BA = bottom ash; FA = fly ash; FGD = flue gas desulfurization sludge.

(b) Includes aluminum, titanium, iron, and silica.

Adapted from *Coal Combustion By-Products Utilization Manual*, Vol. 1: *Evaluating the Utilization Option*, Table 4-1, EPRI CS-3122, Electric Power Research Institute, Palo Alto, California, February 1984.

Fly ash alone, or mixed with cement, can be used to stabilize other materials. The cementitious character of the mixture can be used to agglomerate loose particles, such as soil, or to encapsulate particles. Fly ash-based mixtures have been used to encapsulate materials, such as flue gas desulfurization scrubber sludge, metal processing wastes, and low-level nuclear wastes.

The use of ash for soil conditioning has been a subject of research for many years. The purpose of soil modification is to improve the absorption of nutrients, change the soil pH (reduce acidity), and improve the drainage and water retention characteristics or texture.

4.1.2 Medium Technology Uses

Medium technology uses require fly ash that meets more stringent requirements such as ASTM C618-83. In such applications, fly ash constitutes 5 to 40 percent of the product. Examples of this type of usage are the manufacture of portland cement, substitute for portland cement in concrete, and use as filler material in asphalt. In the past, use of such concrete has been limited to low-strength, slow-hardening concrete. However, recent work at the Canadian Center for Mineral and Energy Technology indicates that high-volume fly ash concrete with 58 percent ash content has developed a 28-day compressive strength of 350 to 630 kg per square centimeter.

Fly Ash in Cement Manufacture

Fly ash has been successfully used at three points in the cement manufacturing process: as a component added to the raw material ahead of the kiln, ground together with cement clinker, and as an additive in the finished cement.

A typical cement kiln feed consists of 73 to 78 percent of limestone (as source of lime), 12 to 17 percent of silica, 2 to 5 percent of alumina, 1 to 3 percent of iron oxide, and 1 to 3 percent magnesium carbonate. Both fly ash and bottom ash are rich in these minerals and can be added to the kiln feed.

Fly ash can also be interground with cement clinker or it can be blended directly with portland cement. ASTM specification C595 for blended hydraulic cements, currently recognizes three types of cements containing a pozzolan (such as fly ash):

- **Type IP.** Portland-pozzolan cement for general construction which may contain 15 to 40 percent of fly ash
- **Type IPM.** Modified portland cement with less than 15 percent fly ash.

- **Type P.** Portland-pozzolan cement for use where early high strength is not essential. Such cement may contain more than 40 percent fly ash.

It is noted that production of one barrel of portland cement (170 kg or 375 lb) consumes about 22 kWh of electricity and thermal energy of about 250,000 kcal (1 million Btu). Blending the portland cement with fly ash could result in substantial energy saving. Thus, a blend of portland cement and fly ash may be sold at significantly lower prices.

Ash in Concrete and Construction Industry

Fly ash and bottom ash are extensively used in the construction industry. Some of the more significant uses include:

- Fly ash as partial replacement in concrete
- Manufacture of light weight aggregate from fly ash
- Manufacture of building blocks

Fly Ash in Concrete

As much as 20 to 30 percent of the portland cement may be replaced with fly ash in conventional concrete construction. The use is limited to applications where early high strength is not required and where the concrete is not exposed to freezing and thawing cycles. Typically, 2.25 kg of fly ash is used to replace 1 kg of portland cement, resulting in significant cost savings. As an example, the Tennessee Valley Authority in the United States has constructed massive dams and other concrete structures, using fly ash as a partial substitute for portland cement.

In addition to the lower material costs, the use of fly ash to concrete mixtures results in improved workability, lower heat of hydration, reduced water requirement, and lower drying shrinkage. The finished concrete has reduced permeability, higher strength, and better resistance to chemical attack (including sulfates).

Fly ash and bottom ash have been extensively used as substitutes for sand and gravel in cement concrete and in bituminous (asphalt-based) concrete.

Light Weight Aggregate

Several processes have been developed to produce aggregate from fly ash. Most processes claim that any type of ash may be used, including those with high carbon content.

In one of the processes developed by Progress Materials Inc. of St. Petersburg, Florida, fly ash is mixed with aqueous calcium hydroxide and pelletized in disk pelletizers. The pellets are then cured at 70C for 12 to 16 hours. The Aardelite Holging B. V. Company of Holland offers complete plants for the manufacture of synthetic light weight aggregate from fly ash, using lime as binder.

Fly ash-based light weight aggregates have found application as a substitute for sand and gravel in concrete, a substitute for gravel in asphalt road surfaces (on city streets), and for insulating material and light weight roofs.

Wisconsin Electric Co. has built a light weight aggregate plant that will utilize all the ash produced in its coal-fired plants. The products will be used in precast concrete and to insulate concrete and mineral fillers.

Bricks and Building Blocks

Several tests have established the technical feasibility of making bricks from a mixture of fly ash and bottom ash with some plastic clay or sodium silicate as binder. A typical composition of ash bricks has 72 percent (by weight) fly ash, 25 percent bottom ash, and 3 percent sodium silicate. The ash bricks are formed with 6 to 8 percent moisture, compared with 20 to 25 percent used in conventional clay bricks. In addition to water savings, the ash bricks offer energy savings in the drying and firing steps. The firing time may be reduced by at least 50 percent. The bricks are 10 to 20 percent lighter than the conventional clay bricks, resulting in easier handling and lower transportation costs.

In England, fly ash was used in the manufacture of a light weight concrete, called autoclaved cellular concrete (ACC). That material was established as a building material in some 40 countries. It may be used in building blocks and reinforced wall and roof panels.

4.1.3 High Technology Uses

Research and development activities are under way in U.S. government and private laboratories aimed at economically extracting valuable or hazardous materials from ash. At the Oak Ridge National Laboratory, research is in progress on processes that can economically extract silica, alumina, and iron oxide. The residue from these processes can be then disposed of in an environmentally safe manner.

Elsewhere, research is attempting to recover valuable elements, such as titanium, manganese, vanadium, boron, and germanium from ash. While the processes are technically feasible, they are far from economic at this time. Attempts are also under way to extract hazardous metals, such as lead, chromium, and manganese.

Fly ash can also be used as a filler in metal composites, such as aluminum graphite and aluminum silicon carbide. Fly ash tends to improve the wear qualities. Cast aluminum-fly ash composites, using inexpensive casting techniques, were produced at the University of Wisconsin. Up to 25 percent (by weight) fly ash was incorporated in Alloy 2014 and A-356 aluminum-silicon casting alloy.

Benefits of these activities are not likely to create a massive demand for ash in the near term.

4.1.4 Research and Marketing Activities

Mathematical models have been developed to predict performance of concrete mixes using fly ash. A computer model can be used in selecting candidate fly ash sources for concrete mix designs (EPRI, 1989). Physical properties of cement-stabilized fly ash slurries were investigated by conducting a laboratory program to identify suitable applications. The results of the laboratory studies indicate favorable usage for fly ash in this industry (EPRI, 1988). Slurry walls are used in many chemical facilities to control groundwater migration and could be high-volume users of fly ash. An EPRI Proceedings Document for ash utilization (EPRI, 1987b) presents a detailed discussion on fundamentals of ash utilization, product research, commercial applications, and international interests in the market.

The American Coal Ash Association (ACAA) promotes uses of coal ash and has represented coal ash producers as well as marketers since 1968. ACAA membership is available in the United States and abroad for interested international organizations (ACAA, 1991). In addition to the ACAA which is a trade association, other commercial entities, such as fly ash contractors are actively involved in transportation, sale, utilization, and proper disposal of ash in the United States. For example, the Trans-Ash Company has moved millions of tons of ash across the United States since the 1970s (TA, 1993).

4.1.5 Economic Considerations

Handling and disposal of ash represent a significant operating cost item for coal-fired power plants. In RENEL plants, the operating and maintenance labor costs and water supply costs are affected. There is a loss of salable power due to pumping power usage and downtime caused by breakdowns. Cost of land for permanent waste storage is also chargeable as cost of generation. It is probable that in the future,

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these costs (particularly those associated with land purchases) will increase. Once all the nearby land is used up, the ash will have to be transported over greater distances for disposal. A more expensive mode of transportation may also have to be employed.

The market value of unimproved ash is quite low. To the buyer, the biggest cost item is the transportation, which limits the distance of use point from the plant. The prospect of sales to greater distances can be improved if the plant can bear a part of the transportation costs (to the limit of savings in operating costs).

The economics may be more attractive if the ash can be converted to more valuable forms, such as light weight aggregate or brick or structural panels. The manufacturing facilities should be built near the ash piles. The value added in these products will allow marketing further away and may even produce some profit. It must be recognized, however, that such ventures will require capital expenditures to construct the new manufacturing plant and to carry out certain retrofit in the power plant itself (e.g., retrofitting for dry ash handling).

The normal process in market-driven economies is to conduct market research and then analyze the economic merits of steps needed to meet the needs of a given market. It is very likely that such analyses will have to be performed on a regional basis. Favorable economics may exist only for a limited number of plants.

In most countries, it was found that successful marketing of ash involved aggressive educational and sales efforts.

4.2 ASH DISPOSAL BY CONTAINMENT

Current western ash disposal practices are driven by two key considerations: protection of the environment, and reduction of the cost of power generation. Sale of ash for industrial use is very important, both environmentally and economically. It reduces land requirement for permanent ash storage, reduces the cost of land reclamation, and decreases the overall cost of ash disposal. Proper containment of disposed ash to ensure protection of human health and the environment is another serious concern. Ash is currently considered a nonhazardous solid waste by the U.S. Environmental Protection Agency (EPA). However, groundwater monitoring is generally required in U.S. ash disposal facilities to verify or confirm that groundwater quality is not adversely impacted by disposal of ash in lined or unlined storage areas.

Wet ash transportation and site operation may be simpler and less expensive for some power plants if the ash storage/disposal facility is on land owned by the plant, or is quite close to the plant. However, if ash disposal land is unavailable immediately near the power plants, "dry disposal systems may be the only economical disposal alternative" (EPRI, 1981). Advantages of the dry system include the following:

- Construction cost of landfills are lower, compared to disposal ponds, since dams and dikes are not required.
- Use of available land space is more efficient since the moisture content of the dry ash can be adjusted for better compaction (higher densities).
- Reclamation of landfills is generally less costly than reclamation of impoundments.
- There is more flexibility in plant operation and ash management.
- Volume of leachate is reduced, minimizing any potentially adverse impact on groundwater.
- Dry ash is more easily accessible for sale if the market demand for commercial use increases in the future.

These advantages not withstanding, a careful economic analysis is required to define the most advantageous option for a given plant. In new installations, the economic benefits of dry ash collection and transport are readily evident since the plant can be initially equipped for dry ash handling. However, in existing plants already operating on a wet basis, there is a significant capital expenditure to retrofit the ash handling system.

As discussed above, only a fraction of the ash is used for industrial or commercial purposes; the remaining captured dry ash is mainly landfilled. Moisture is added to the ash at the landfill during compaction. This helps adjust the moisture content of the ash to achieve better compactability. Fly ash can be compacted to higher densities more efficiently and more economically if it is compacted at near optimum moisture content. Higher densities of ash, in turn, allow more efficient and economic use of the premium landfill space.

4.2.1 Western Ash Disposal Practices

Excess ash in the United States is disposed off by permanent storage in surface impoundments or landfills. Ash piles are not commonly used. Approximately 48 percent of the coal-fired power plants in the United States convey fly ash pneumatically to temporary storage silos for later sale or ultimate disposal at on-site or off-site landfills. The remaining plants (52 percent of the plants in the United States) sluice the ash to settling ponds for ultimate storage and containment (EPRI, 1987). The impoundments are almost always on site, consisting of a primary pond and, at least, one discharge pond. The treated water from the discharge pond is usually recycled or discharged in the surface waters (rivers) under special permits from the state agencies.

The sizes of these ponds are typically on the order of 50 to 400 acres (20 to 160 hectares), depending on the plant operation and site location. The operation of a 1000-MW power plant in the midwest United States is cited as a typical example. The primary pond at this plant has a capacity of about 280 acres (113 hectares). This pond received approximately 10 million cubic meters of ash (fly ash and bottom ash) over a period of 20 years at a rate of approximately 500,000 cubic meters of ash per year. The pond was divided into two segments by a dike and an upper and a lower pond. The lower pond was connected to the discharge pond; both of these ponds were unlined (EPRI, 1992).

Comanagement of Wastes

Some power plants dispose of their combustion by-products collectively in a single disposal facility, a practice generally referred to as comanagement of wastes. The by-product includes both the high-volume wastes (such as coal ash) and low-volume wastes (such as boiler cleaning liquids and waste treatment sludges). Nationwide, about 80 percent of the by-products are disposed of either in ponds or landfills. Ponds account for approximately 44 percent of the management facilities (EPRI, 1991). This percentage has varied over the years. For example, in 1974, statistical data indicate that 30 percent of ash was trucked to disposal sites and 70 percent was sluiced to ponds; whereas, in 1978, the data indicate that 49 percent was trucked offsite and 51 percent was sluiced to the ponds (EPRI, 1987). It is apparent that the trend has been to more trucking (dry collection), and less sluicing.

Comanagement of coal combustion by-product in the southeastern the United States is cited as another typical example of power plant operation in the region where three pond sites were selectively studied for ash management practices (EPRI, 1991). A disposal pond system typically consists of two settling basins (primary and secondary ponds). The ponds at the selected sites were not lined. The ponds at one site were located in a bedrock valley with residual soils; the ponds at another site were situated in an alluvial valley. Ash at one site was slightly acidic to neutral, while ash at the other site was alkaline. The ponds in the bedrock valley, constructed in 1973, had a total surface area of approximately 60 acres (24 hectares), receiving ash from a 400-MW power plant at an annual rate of about 30,000 cubic yards (23,000 cubic meters). Over a period of 16 years, approximately 500,000 cubic yards (380,000 cubic meters) of ash were sluiced in the 60-acre pond system (EPRI, 1991).

Sluice Water

The quantity of ash generated at a typical 1000-MW power plant in the United States may vary from about 180,000 metric tons per year (tpy) if the plant is using coal to about 340,000 tpy if the plant is using lignite (EPRI, 1987). The volume of generated ash is difficult to estimate for a typical plant as the volume depends on many factors, including quality of coal, plant efficiency, and plant operational features. However, making certain assumptions, it may be estimated that the ash generated in a 1000-MW power plant may amount to about 300,000 tons of solids per year. Wet sluicing the ash at such a plant may generate approximately 900 million gallons per year of sluice water: a ratio by weight of 12.5 parts water per one part ash (EPRI, 1991). This is a large volume of water to manage, considering the quantities of ash generated annually in the United States. In 1990 alone, the U.S. electric utilities generated approximately 64 million metric tons of coal ash (Table 4-1).

Ash in the United States is sluiced at a solid content of 5 to 15 percent by weight. Reduction of water may have potential savings in energy consumption, cost, and environmental benefits. It is important to recognize that reduction of water in the sluice should not be done without corresponding reduction of the pumping time so as to maintain adequate flow velocity in the sluice pipes. Reduction of flow velocity increases the chances of ash settlement during the transport which would, in turn, plug the conduits, and could result in extra cost of delays, repairs, and replacement of parts. Therefore, cost savings from water reduction is always weighed against risk of ash deposition and plugging.

Another measure for cost savings and realization of environmental benefits is to recycle most of the sluice water. For example, a midwestern utility which operates 10 power plants in the region, typically recycles 80 to 90 percent of sluice water. In addition, the midwestern utility has retrofitted all of its power plants with dry ash handling systems to reduce use of water and take advantage of dry disposal systems (EPRI, 1987).

Dry Collection

Concern with dry collection has been mainly dust control at the plant and during the landfilling operation. Spraying water is common for dust control measures. However, water spraying at the plants is avoided in some cases because of the pozzolanic nature of some fly ash which sets up as a result of moisture and makes it difficult to remove the ash from temporary storage silos. In such circumstances, the fly ash is blown dry in the temporary silos or bins, and wetting is done during or after the ash is loaded on the trucks for shipment to the ultimate disposal site (EPRI, 1987). In some cases, other dust suppressant chemicals may be used such as the polymeric surface binders by Chem-Jet Inc. During the placement of ash in a landfill, it is generally required that the ash be kept covered with a layer of soil or liner except for a limited area needed for the daily operation.

Leachate Control

When filled to capacity, ponds or landfills are capped with a layered soil system and reclaimed as described in Section 4.3. In addition to dust control, the function of the cap is to limit direct public access to the ash, minimize precipitation leaching into the subgrade, and reduce any potential for adverse environmental impact.

Although coal ash is considered nonhazardous, groundwater in U.S. disposal sites is regularly monitored to ascertain the impact of ash leachate. This topic is discussed in the next Subsection 4.2.3. The chemistry of leachate depends on various factors, including the soil attenuation, availability of water, and the chemical content of ash which varies from plant to plant. To develop typical values for ash chemistry during one study, a group of 40 fly ash bulk samples was obtained from coal-burning power plants across the continental United States. Four of these fly ash samples were selected for detail laboratory analysis as summarized in Table 4-3. The analyses revealed 28 trace elements in fly ash (fresh or weathered). Boron was found to be the most mobile element. Vanadium, chromium, and arsenic and other elements were also detected as shown in Table 4-3.

Leachate control in the landfills and in the ash ponds with large volumes of sluice water has been a major consideration with ash management practices in the United States. Although most of the ponds and landfills used for ash disposal in the United States were unlined in the past, the modern trend is to line the ponds or to switch to dry collection system.

4.2.3 U.S. Environmental Regulations

In late August of 1993, the U.S. EPA ruled that coal combustion by-products (fly ash, bottom ash, boiler slag, and flue gas emission control wastes) generated at the electric utility power plants should not be regulated as hazardous waste under the Resource Conservation and Recovery Act (RCRA).

Table 4-3
Elemental Concentrations in Bulk Fly Ashes in the United States

Elements	W102	W104 % by Weight	W112	W131
Al	10.3	12.6	9.3	14.0
Si	20.2	19.9	23.6	20.8
Fe	17.7	8.2	13.7	6.5
Ca	1.1	0.9	3.3	1.0
Mg	0.5	0.4	0.6	0.6
Na	0.3	0.3	1.3	0.4
K	2.2	1.6	1.7	2.1
S	1.0	0.4	0.8	0.5
		µg/g		
As	126	204	16	171
Cr	294	170	441	141
Cu	139	202	90	165
Pb	82	118	48	87
Se	<3	7	9	10
V	459	315	254	243
Zn	442	258	510	153

Source: EPRI, 1990

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Approximately 70 percent of all coal ash in the United States is generated in 17 states of which 14 regulate coal ash as solid wastes. Liner installation is a mandatory requirement in 12 states, and 16 states have waste management requirements for coal ash. The U.S. EPA feels that the state programs for coal ash management are adequate and improving (DER, 1993). Therefore, local state regulations will probably dominate management of ash as nonhazardous industrial waste, adopting the federal regulations (Subtitle D of RCRA) as minimum requirements.

Whether the disposal facilities (ponds or landfills) are lined or unlined, a major concern is to verify and confirm that the generated leachate, if any, does not have statistically significant impact on the downgradient groundwater. Unless it is certain that the subsoil is quite impermeable, the groundwater downgradient of the ash disposal facilities is regularly monitored for indicator parameters or site-specific constituents of concern.

4.2.4 Current Ash Disposal Practices in the United States

The current ash disposal practices in the United States are designed to satisfy the RCRA Subtitle D requirements for reasons discussed in the previous subsection. RCRA Subtitle D generally requires that the waste be "contained" in such a way as to prevent migration of waste to air, soil, and groundwater to the degree that it may be harmful to human health and the environment. Each state has its own requirements for particulate emission standards which would mandate dust control and covering the waste during operation and closure of the ash disposal facilities (ponds or landfills).

Subtitle D requirements generally translate into a site-specific groundwater monitoring program, a bottom liner, and a cap cover system over the waste once the pond or landfill is filled to capacity. The liner, when required, has to be compatible with the waste and chemically resistant for long-term performance. During one investigation, 14 types of liners were studied for compatibility with ash. The investigation results indicated that, compared to the other 13 liners, the high-density polyethylene (HDPE) liner showed the least amount of change after long-term exposure to coal-fire wastes (EPRI, 1989). Long-term exposure tests have been developed for selecting compatible liners for coal-fired ash disposal facilities (EPRI, 1987a).

Depending on the local geohydrology, a synthetic liner at the bottom of the pond or landfill may be omitted if it can be demonstrated by design and/or monitoring that the objectives of Subtitle D can be achieved without a liner. The groundwater monitoring system may consist of three downgradient wells and one upgradient well, although number and configuration of wells are heavily dependent on the site geohydrology.

Once the pond or landfill is filled to capacity, the facility is closed under the minimum requirement of Subtitle D. The cap cover system generally consists of several feet of soil with or without liner and a drainage system depending on the climatologic conditions at the site as negotiated with the local state environmental agencies. The cover usually consists of grass; however, asphalt or concrete may be designed for parts or all of the cover provided the objectives of Subtitle D are satisfied. The cover material may be designed to suit the facility owner's real estate needs, such as parking, storage, landscape, or recreation. However, reclamation of the closed facility may be dictated by other factors, such as the value of real estate in the area, environmental demands imposed by the local community, and future land-use plans.

4.3 MODERN LAND RECLAMATION PRACTICES

Modern reclamation practices consist of containing the ash and developing the cover surface for commercial/industrial use, recreation, or wildlife habitat. Landfills are converted to golf courses, artificial ski centers, sport centers, parks, and recreational areas. Some disposal sites are revegetated to restore back to natural states for wildlife support and game resorts. The disposal facilities are also successfully converted to parking lots, shopping centers, manufacturing facilities, and other commercial developments where land is at a premium. One of the most frequently desired and least expensive methods of reclaiming ash disposal sites is re-vegetation, although some of the surface area may be paved for commercial/industrial use.

4.3.1 Revegetation

Containment of ash, as described in Section 4.2, has precedence over any reclamation requirements. However, reclamation activities can be performed together with the containment activities to satisfy environmental concerns and land use planning requirements. Combining the containment and reclamation needs could be an attractive cost-cutting option. An ash landfill reclamation program in the state of Arkansas is cited below (Snow, 1993) as an example of combining reclamation and containment activities to realize cost savings.

AP&L Reclamation

As a result of an environmental impact study conducted for the White Bluff power plants in the state of Arkansas, the utility company, Arkansas Power and Light Company (AP&L), was committed to reclaim its coal ash disposal site in Arkansas and restore the original vegetation. The state permit requirements for the White Bluff reclamation consisted of a daily soil cover over the ash as it was disposed of in the landfill, and a final soil cover to support vegetation; the required thickness of the final soil cover was 30 inches. The state had estimated that the cost of this cover system in 1982 dollar values would be approximately $7,000 per acre ($17,000 per hectare).

As a cost-cutting measure, AP&L conducted an ash reclamation research program which successfully demonstrated that test plots with 6-inch and 12-inch soil covers had the best vegetation growth. As a result, the state issued a variance to the original permit requirements, granting a reduction in thickness of the final soil cover from the originally specified 30 inches to a revised thickness of 12 inches. This variance was estimated to drop the cost (in 1982 dollars) from $7,000 per acre down to $4,000 per acre ($10, 000 per hectare). This was a cost saving of more than 0.5 million dollars over the life of the ash disposal landfill site which occupied an area of approximately 110 acres (45 hectares). The ash landfill was successfully restored to support a luxuriant growth of perennial native Arkansas switch grass, providing cover for the landfill and food for the wildlife (Snow, 1993).

The AP&L ash reclamation research program was the most extensive program ever performed in the United to evaluate plant adaptability to ash reclamation sites. The program was initiated in early 1982 by starting a greenhouse testing setup and using potential reclamation plant materials. The program was conducted jointly by AP&L and the Soil Conservation Service Plant Material Center of the U.S. Department of Agriculture at Coffeyville, Mississippi. Prior to this program, the Central Electric Generating Board (CEGB) of the United Kingdom had developed feasible and economic methods for reclamation of coal ash wastes. The CEGB had successfully minimized the amount of soil needed for reclamation, and identified plant species that could grow in coal ash/soil matrix. For economic considerations and expediency, the AP&L research program adopted most of the CEGB reclamation methods applied previously.

The AP&L program involved screening over 100 plants to study the growth potential in ash and soil/ash mixtures. The study revealed many species potentially adaptable for reclamation of the White Bluff landfill site. Thirty-two types of grass/legumes and 17 species of trees/shrubs were planted in replicates; these were planted in five test plots occupying a 1-acre parcel of land at the White Bluff site.

The test plots were set up to field test the adapted materials for site reclamation, evaluate effect of fertilizers on the selected species, and determine minimum soil coverage required for ash reclamation.

The test plots were set up measuring 60 feet by 100 feet on plan dimensions (18 by 30 meters). Each plot was subdivided into 40 subplots and used for various selected plants. One of the test plots was used as a control plot where no soil was added to the ash, planting directly in the ash. In the other four test plots, the ash was disked to break the cementitious surface before it was blended with acidic clay soils. The thickness of blended soil (soil cover) in each test plot was different: 12 inches of soil cover in one plot, 6 inches in the second plot, 3 inches in the third plot, and only 1 inch in the fourth plot. Each plot was fertilized using 50 pounds of fertilizer (10-20-10 brand) per plot. Eleven grass/legume species were identified having the best growth. Only one of the tree species (Black Locust or *Robinia pseudoacacia*) proved successful in long-term survival and adaptability to ash.

As a result of the above studies, AP&L was successful in disposing of the unmarketable coal ash in a landfill, restoring the native vegetation, and transforming the site to a prairie recreation area covered with luxuriant grass and wildflowers. The protected prairie habitat now supports a variety of game and non-game animals. More than 1,600,000 tons (1,455,000 metric tons) of ash has been landfilled on site so far. However, thanks to aggressive marketing, approximately 70 percent of the AP&L coal ash is sold for off-site recycling; this is much higher than the national average of 30 percent (Table 3-1). Thus, AP&L has "turned a $300,000 annual coal ash disposal expense into a $400,000 annual profit" (Snow, 1993).

Plant Growth in Ash

Plant growth in ash is limited by five major factors: cementing properties of fly ash, salinity, pH value, deficiency of macro nutrients, and presence of excessive trace elements. Gas exchange and rooting depths are severely limited by fly ash cementation. Presence of soluble salts (sodium and calcium) in the ash restrict the plant water uptake, resulting in nutrient deficiencies. The pH of fresh coal ash is usually greater than 12 which is outside the ideal soil pH range of 6 to 7. Although coal ash is generally well supplied with phosphorous and potassium (two major macro nutrients), they are not present in chemical forms easily available for the plant. Another major macro nutrient, nitrogen, is totally lacking in ash. Finally, trace elements in the ash are sources of concern. For example, boron is a plant nutrient if it is present in very small amounts. However, excessive amounts of boron found in coal ash could be the most severely limiting factor for plant growth in ash reclamation sites.

To have long-term success, a reclamation program has to be developed for climatologic conditions of each region. A successful reclamation program would include selecting the right plant species, designing correct soil/ash mixture, application of proper fertilizers, developing well-engineered landscaping, and planning an economic irrigation scheme.

4.3.2 Engineering Considerations

Restoration of most ash disposal sites in the United States involves closure of ponds or landfill sites, both of which contain substantial amount of ash below grade. As discussed earlier, ash piles are not common in the United States. Engineering considerations for most of these sites consist mainly of designing a cap for containment/reclamation, developing erosion control measures mainly though proper grading, designing surface and subsurface drainage systems, selecting proper dust control measures, and providing slope protection plans. These and other engineering considerations are discussed in the following subsections.

Cap Design

Clayey soils are generally selected for cap design to prevent excessive infiltration of irrigation water or precipitation through the cap. The pH value and the type of top soil are also dictated by the vegetation cover selected for the cap. A geomembrane liner is sometimes used in combination with the clay soil to further reduce permeability of the cap. Any excess run-off or excess infiltration is generally collected by a surface or subsurface drainage system which may include a synthetic geodrain or a layer of drainage material.

The cap grading is generally limited to 2 or 3 percent to control erosion caused by surface run-off. On steeper side slopes, light weigh synthetic mats (such as Enkamat) are sometimes used to protect erosion and promote heavy plant growth. Enkamat (one of many brand names) is a flexible lightweight geomatrix of nylon mono filaments fused together such that approximately 90 percent of the geomatrix is open space. The mat is available in thickness ranges of 0.4 to 0.75 inches (1 to 2 cm). The synthetic mat provides considerable open space for anchorage of the root system on the slopes. Once the root system holds, the vegetation takes over and provides a natural erosion control. The mat is then hidden underneath this thick vegetation while still retarding the water flow and reducing erosion (AEC, 1993).

Other erosion control blankets are available in the market, such as Hi-Velocity Curlex Blankets. If vegetation is not desirable on sloped areas, flexible concrete revetment blocks could be used for erosion protection; one brand name for such revetments is Tri-lock (AEC, 1993). Ash could be used in constructing these revetment blocks to save costs and promote industrial use for the ash. As another measure of control against erosion by rain or wind, the slopes may be spray coated with special compounds. Such compounds are discussed under the dust control measures in the next subsection.

Dust Control

Johnson March Systems Inc. is marketing a dust control product (Compound SP) for protection of stockpiles of cinders, fly ash, and other similar dusty fine materials stored outdoors. Compound SP is a blend of synthetic, organic, long chain of polymers in a water base. The SP compound, when sprayed on the pile surface, binds the top most particles to one another and develops a surface crust. The compound acts as a surface binder forming an interlocking polymer chain to create a flexible surface crust. The crust is tough, durable, and resistant to the wind or rain action. Because the moisture can still penetrate the surface crust, heavy run-off is avoided and erosion is forestalled. Thus, the crust controls gutting of the pile surface due to heavy winds and rainstorms (JMS, 1989).

The surface crust achieves a high degree of elasticity, providing a long life expectancy for the crust. A single application of compound SP 301 to the pile surface will provide protection for a period of 6 months to a year. Another product (SP 400) provides effective protection for a period of up to 4 years. The life expectancy of the crust depends, to a large extent on the climatic conditions as long as the crust surface is not disturbed by animals, equipment, or people. If the surface is disturbed, the localized area is re-sprayed to patch up the surface crust. Thus, the slope surface can be re-sprayed locally and periodically. As an alternative for re-spraying, the surface crust can also be seeded for vegetation. Germination of seeds in the crust is possible since the crust is porous, allowing rainfall penetration and air flow through the crust (JMS, 1989).

The normal application rate for Compound SP is 1 gallon per 100 square feet (0.4 liters per square meter) of surface area, costing approximately 9 cents per square foot ($1 per square meter). The compound is applied undiluted as it is received from the supplier. It may be applied with any type of spraying equipment. To avoid wash off and rain dilution, there should be no rainfall on the sprayed surface within 24 hours of application (JMS, 1989).

Compound SP was first used successfully in 1982 at a refractory site in California. Laboratory analyses performed by the product users indicated that the organic surface binder had no adverse environmental impact. The residue and ash content analyses have confirmed that the organic binder produces a non-toxic ashless combustion residue (Zanko, 1984).

Another compound marketed by Johnson March Systems, Inc. is a dust suppressant (Compound M-R) which dampens and agglomerates the dust particles, making them too heavy to be airborne. The treated material can be handled for storage or reclamation almost dust free. The compound uses less than 1 percent moisture with a normal application rate of one part M-R to 1,000 parts water. Compound M-R, when mixed with water, lowers the surface tension of water from 75 dynes/cm to below 25 dynes/cm. This drop in surface tension provides tremendous wetting and penetrating power to the mix. The dust suppression effect of Compound M-R, if properly applied, is carried over through handling, storage, and reclamation (JMS, 1989).

Although Compound M-R acts as a dust suppressant, it does not provide protection against rain or wind erosion since it does not provide a crust similar to what is provided by Compound SP described earlier. Therefore, application strategy for the two types of compounds are different. While SP is applied on the surface of a stockpile, Compound M-R is applied on the material as it is being handled prior to stockpiling.

The current market price for Compound M-R is approximately $6 per gallon ($1.60 per liter), depending on the size of purchase order. At this price, the material cost would be approximately $1 per 150 tons of treated ash, using 0.5 percent moisture content by weight of dry ash and a normal mix proportion (one part M-R to 1,000 parts water). This cost does not include shipment of material to the site or minimal cost of spraying.

Many dust suppressant materials are available in the market to efficiently control the dust without using excessive water. While water can be used as a dust suppressant, it has several disadvantages, such as requiring frequent re-allocation, acting as a vehicle for transport of possible contaminants, and contributing to production of leachate. Under some circumstances, using dust suppressant products may be more cost effective than using water if the long-term expenditures and liabilities are factored in the cost/benefit analysis.

Other Considerations

Other engineering and design considerations for site restoration may include slope stability problems, liquefaction potential due to earthquakes, and additional containment features such as installation of slurry walls or subsurface grouting.

Postconstruction slope failures (after restoration is complete) could be of main concern for ash piles as they are constructed above grade. Concerns over such slope failures are much less pronounced if the ash is buried underground in a closed pond or a landfill. However, postconstruction slope failures are considered for landfills or ponds, especially if they are constructed partially above ground; for example, where a dam is placed at one side of a valley to provide enclosure for the pond or where a berm is constructed on the side of a hill to create a landfill.

If the disposal facility is restored for commercial/industrial developments, settlement of the ash under anticipated future loading is evaluated and incorporated in the design. In active seismic areas, damages due to liquefaction of the ash have to be evaluated also.

In addition to capping, other containment measures may be required if the disposal facility is suspected to be a potential source of contamination. A likely source of contamination could be an unlined ash disposal site constructed close to the groundwater table or close to a body of water. These containment measures may include slurry walls or partial subsurface grouting to cut off the contamination source or reduce rates of contaminant migration. However, such containment measures are the exception rather than the rule at the U.S. ash disposal facilities.

4.4 CONCLUSIONS AND RECOMMENDATIONS

Ash generated by the coal-fired power plants in Romania is mostly stockpiled outdoors for ultimate disposal. A detailed inventory of the existing ash disposal facilities is not available at this time. However, it is estimated that the total area of the existing ash disposal sites for the entire country (20 coal-fired power plants) may be on the order of 6,000 acres (2,400 hectares). Most of these past disposal sites have not been successfully reclaimed for land re-utilization. The surrounding land owners are now unwilling to sell land for ash disposal, and the power plant industry is facing a shortage of land for future ash disposal. In some areas of the country, the land shortage is threatening the continued operation of the power plants. This problem will continue unless drastic modifications are made to the current ash management practices within the next few years.

The current rate of ash generated by Romanian coal-fired power plants is approximately 15 million metric tons per year. Ash generated at this rate would take up nearly 150 acres (60 hectares) of land per year using current disposal practices. Because of land shortage, such a rate of land consumption cannot be tolerated unless the land is reclaimed at similar rates for successful reuse and/or the

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ash management practices are significantly improved to reduce the future land needs for ash disposal.

This section presents general and conceptual plans recommended to improve the current ash management practices of coal-fired power plants in Romania. These conclusions and recommendations are based on limited data and, therefore, cannot be used as detailed design. Although detailed cost analysis is not within the scope of this report, cost values are provided in some cases for comparison and discussion purposes only. Obviously, material and labor costs vary significantly depending on many factors including geographic location, design details, project size, market conditions, and contractual details.

The past ash management practices generally favor minimum capital expenditure even if the long-term costs are high or unknown; this tendency is specially pronounced in cash-starving economies. However, initial capital investment is unavoidable if the current ash management practices are to be modernized in order to realize considerable long-term cost savings. In developing our recommendations, we have tried to avoid capital intensive options and considered only the practical options appropriate for Romania. Minimum modifications are recommended for the past ash disposal sites to avoid excessive capital expenditure. However, significant changes are recommended for future ash disposal practices to alleviate the majority of ash management problems currently facing the coal-fired power plants in Romania. The proposed plans for the past disposal sites are discussed in Subsection 4.4.1. Recommendations for future ash disposal practices are presented in Subsection 4.4.2. The last subsection (4.4.3) provides a list of follow-on studies and steps required to implement the recommended improvements.

4.4.1 Past Disposal Sites

The past disposal sites consist mainly of ash piles approximately 100 feet high with side slopes roughly at 3:1 (horizontal to vertical). It is recommended to revegetate the entire surface of these piles as a measure to control dust and minimize erosion. Use of special mats (such as Enkamats) may be required on some steep slopes to anchor the initial root systems. Several inches of clayey soil cover will be required to blend in with the surface ash to minimize excessive loss of irrigation water. Ash is very permeable and direct irrigation on ash is not only wasteful because of excessive water loss, but it could also contribute to leachate production and transport of soluble chemicals to the groundwater.

If properly applied, farming the ash piles as a method of land reclamation could be more economical than revegetation. To have long-term success, a reclamation program has to be developed for climatologic conditions of each region. In addition, the program should also adopt the right plant species, use correct blend of soil/ash mixture, select proper fertilizers, and develop well-engineered landscapes with economic irrigation schemes. Also, in Romania, farming the ash piles should be encouraged by conducting special public relations (PR) programs and promoting community awareness. The farmers' concerns over the potential carcinogenic effects of radioactive materials in the ash deposits should be corrected by presenting data to the community through public meetings and special educational documentaries, and by investing in PR efforts through the public telecommunication systems (direct telephone, radio, and television). Public education and participation are crucial in promoting farming and agriculture on the ash piles.

Some of the ash piles can be reclaimed by the utility companies as pilot projects, restoring the land to recreational parks or wildlife habitats as discussed in the earlier Section 4.3. Such reclamation projects may be more costly than farming, but the investment would pay off by gaining the public confidence and encouraging farming. These pilot project sites could also be used as test plots to select the most feasible reclamation methods for the particular local geographic conditions.

The height of the ash piles can be increased, the slopes can be cut back by using special engineering materials, and some of the ash could be relocated to provide more open space. However, such measures could be very costly and the cost may not be justified unless the land is exceptionally expensive. Therefore, such drastic measures are not recommended for the past ash piles. However, such measures could be further explored for exceptional site conditions.

4.4.2 Future Disposal Practices

Landfills and Impoundments

The use of landfills and impoundments, rather than ash piles, is recommended for future ash disposal. This would be a major deviation from the current practice of disposing of ash almost exclusively at ash pile disposal sites. While most of the ash is kept above ground at ash pile disposal sites, ash is contained and buried mainly below ground in impoundments and landfill sites. There are several advantages and long-term benefits to disposal by containment (landfills or impoundments). Construction of a landfill or an impoundment requires a relatively high initial capital expenditure for excavation and soil stockpiling. However, construction of ash pile disposal facilities is not substantially cheaper, considering the cost of labor and material required to complete the perimeter berms which are constructed in stages. Furthermore, excavation could be minimized in most sites by taking advantage of the natural topography. For example, some containment sites are constructed by berming up the side of a hill or placing a dike at lower point of a valley.

The soil excavated for construction of a landfill or an impoundment could be used for on-site construction or landscaping, sold or given away for free haul-off, easily seeded for reclamation, and/or used for closure of the ash disposal facility (landfill or impoundment) when the storage capacity is depleted. While some surplus stockpile of soil may remain above grade at a landfill or impoundment site, huge piles of ash remain above grade at an ash pile disposal site. Reclamation, removal or reuse of surplus soil stockpiles would be considerably easier and less expensive than maintenance or reclamation of a huge pile of ash. None of the above options for soil stockpiles can be easily implemented for ash piles which could be a constant source of pollution requiring costly remedies and taking up a large tract of land with little or no use.

Reclaiming Ash Piles

Reclamation of an ash pile is considerably more expensive than reclamation of a landfill or an impoundments since considerable slope areas are involved with the ash piles. Once reclamation is completed, the reclaimed ash pile has several disadvantages over the reclaimed landfill or impoundment. The elevation at the top of the pile is considerably higher than the adjacent farm lands, requiring additional cost of pumping for irrigation water. Farming on a hill side is more difficult than on the flat farm lands. Furthermore, the major elevation difference is a psychological barrier to the farmers who are not willing to swap their flat farm lands and move on to cultivate on top of anomalous hills in the landscape which are created by the ash piles. On the other hand, reclaimed landfills and impoundments are generally flat and blend in well with the natural topography without creating anomalous hills.

Sluicing the Ash

Sluicing the ash (slurry) to the impoundments and landfills requires considerably less energy and costs much less than pumping the slurry uphill to top of the ash piles. Pumping gets progressively more difficult as the ash piles build up and the disposal facility reaches near capacity. No such progressive pumping load is developed as the impoundments or landfills approach their capacities. Therefore, cost of pumping and maintenance is considerably higher for the ash piles. The ratio of water to ash has to be higher and the slurry has to be more fluid at the ash pile disposal sites to facilitate more strenuous pumping demands. Higher water ratios increase pumping costs, result in additional wasteful water loss, and create extra leachate for potential transport of more contaminants.

It is more feasible to recycle sluice water from an impoundment than from an ash pile facility because water is contained better in a pond. Landfills have the additional advantage that the ash can be transported dry and compacted. During the placement of the ash in the landfill, the moisture on the dry ash can be adjusted to achieve higher compaction and reduce storage space requirements. One ton of loosely dumped coal ash requires approximately 1.25 cubic yards (0.95 cubic meters) of storage space. The same ash, properly compacted at its optimum moisture content, requires only about 0.8 cubic yards (0.60 cubic meters) of space (Loftus, 1976). This is a saving of approximately 35 percent in the required storage space, a tremendous benefit over a long-term operation.

Dry Handling at Disposal Facilities

Dry handling of ash at the disposal facilities eliminates the cost of water consumption, recycling, and leachate control. This is a significant cost saving although some capital investment will be necessary for dust control measures, such as spraying dust suppressants. Another advantage of the dry handling system is that the dry ash disposal operations can be easily adjusted to match the ash market fluctuations. As discussed in Subsection 4.2.1, the trend in U.S. ash management practices has been increasingly towards the dry system as the power plants were modernized. Obviously, dry ash landfill operation cannot be an optimal economic option for every power plant. Therefore, it is recommended to assess individual cases for each power plant to select an appropriate disposal option. Wherever possible, it is recommended to convert the future operations from ash piles to impoundments or landfills, using wet or preferably dry collection systems. The ash handling system within the power plant facility has to be coordinated with the operation at the selected disposal facility.

Transportation/Disposal

Dry transportation of ash and disposal at an independent off-site landfill may be an economically attractive option when land acquisition immediately close to the power plant is not feasible. Long-term independent transporters may be used for hauling ash in dumper trucks or pneumatic pressurized tankers. Similar independent transport companies in the United States (TA, 1993) haul ash for utility companies at rates of about 10 to 50 cents per ton per loaded mile, depending on the location, distance, and volume.

Another significant improvement for ash disposal problems can be realized by using the dedicated trucks delivering coal to the power plants. Rather than leaving the plants empty, these trucks could be used to haul off ash to the coal mines and use ash for land restoration. This can be accomplished only if the coal mines are strictly required to reclaim the mined areas. The enforcement of reclamation at the coal mines may be encouraged by promoting public awareness, impacting local policies, preparing stricter specifications for mining, and aggressive marketing.

Commercial/Industrial Use

It is also recommended to invest on aggressive marketing effort to promote commercial/industrial use for the dry ash. As described earlier, the U.S. national average for industrial use of ash is approximately 30 percent of the coal ash generated by the power plants (Table 4-1). Through aggressive marketing, a U.S. utility company was successful in selling approximately 70 percent of its generated coal ash for industrial use, as discussed earlier in Section 4.1.

The available information indicates that the national average for industrial use of ash in Romania is less than 1 percent of the generated coal ash by the country's power plants. This is extremely low and does not compare with either 30 percent or 70 percent values cited above. It is clear that investment in aggressive marketing is needed to promote industrial use of ash in Romania. The impact of establishing a larger market for industrial use of ash could be major savings in disposal cost of ash, significant reduction in storage space requirements, and major decrease in land needs for future ash disposal.

In the United States, independent companies such as Trans Ash (TA, 1993) bid to haul off fly ash from the utility sites. The price of fly ash in the eastern United States is currently about $5 per ton for class F ash (non cementitious) and $10 per ton for Class C (cementitious). The cost varies with the market fluctuations and sometimes utilities take bids for free haul. These independent companies help develop markets for the ash, buy it from the utilities, transport the ash, and sell it to the end users. Also, as a trade association, the ACAA promotes markets for industrial and commercial use of coal ash. The ACAA has international members and represents many entities, including utility and coal companies (ACAA, 1991).

RENEL could promote market for coal ash use in Romania by seeking membership with trade associations such as ACAA and by assisting or encouraging independent contractors to engage in ash marketing. Companies, such as Trans Ash (TA, 1993), may be solicited to initiate an ash transport and marketing network in the country. A list of potential markets for industrial use of ash was provided in Section 4.1.

This list should be aggressively explored in Romania, updated, and regularly adjusted for suitable market in the country.

4.4.3 Further Studies

A detailed inventory of the existing ash disposal facilities would be necessary to assess the required extent of land restoration and plant modification. The inventory should be prepared using aerial photos and/or topographic maps to indicate land features immediately surrounding each facility site. The geology and geohydrology of each site has to be determined to evaluate excavation conditions, permeabilities of the subsurface soils, and groundwater conditions including groundwater flow direction, flow rates, and water table fluctuation ranges. Sites with shallow groundwater tables should collect sufficient chemical data on the groundwater samples to assess potential contamination and establish basis for future groundwater monitoring. Samples from ash pile leachate should be analyzed to determine soluble chemicals of concern, if any. Specific information on production rates and ash properties will be required from each power plant. Based on these data, a site assessment report (SAR) has to be developed for each power plant requiring modernization.

The SAR should also include sufficient information on the regional geography, climatic conditions, agriculture, ecology, and pertinent environmental conditions. Based on the SAR, engineering plans can be developed for modification of each power plant to implement recommended improvements to the ash management practices. An initial cost estimate could then be developed for the engineering plans and presented for approval of the RENEL authorities. Based on comments from the RENEL authorities, the engineering plans would have to be finalized. A set of construction specifications and drawings could then be developed to accompany the bid documents for selecting contractors and vendors to execute the project.

The follow-on studies and steps required to implement the recommended modifications are briefly listed below:

1) Prepare an SAR for each power plant which requires modernization
2) Conduct soil exploration and install monitoring wells if necessary
3) Identify specific modifications for each plant based on SAR and specifics of the plant operation
4) Develop engineering plans
5) Develop initial cost estimate for the engineering plans
6) Present the engineering plans and cost estimate for RENEL approval

7) Finalize the engineering plans based on comments from RENEL
8) Develop specifications and construction drawings
9) Develop bid documents and select contractors/vendors
10) Implement the final engineering plans

Activities preceding the actual implementation of plans (Items 1 through 9 above) may take 1 or 2 years, depending on the extent of modifications required for any particular site. Additional time would be required for actual implementation of work which could take from 6 months to 24 months to complete, depending on the extent of modifications planned. Therefore, it may be several years before implementation of work is completed at some of the power plants.

As discussed earlier in this report, some power plants have less than 5 years to continue operation before the available land for ash disposal is depleted. Implementation of the approved plan has to be completed within this critical period of 5 years if the power plan operation is to continue without interruption. Therefore, any site assessment and engineering planning should be initiated expeditiously considering the estimated schedule of activities provided above. Also, the power plants should be prioritized on the basis of their needs for modernization. This prioritization would help allocate appropriate schedule time and budget for reclamation of the existing disposal facilities and modernization of ash management practices at each plant.

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Section 5

Western Experience with Ash Handling Systems

This section discusses experience and practices with ash handling in coal-fired power plants in the United States and in other western countries. The evolution of systems and practices for ash collection and handling. Also discussed are the characteristics and operation of modern methods.

5.1 ASH COLLECTION

Coal furnished as fuel to power plants contains varying proportions of incombustible materials. Some of these materials are intimately dispersed in the carbon matrix, others are mixed in during mining operations and are shipped to the power plants. These materials form a residue in the combustion process. In a typical pulverized coal burning furnace, ash is generated mainly in the furnace. A portion of this ash is collected in the furnace bottom. This fraction usually constitutes approximately 20 percent of the total and is appropriately called "bottom ash." Some ash is also collected in hoppers below the economizer and air heater and finally in the precipitator. This ash is referred to as fly ash. Rocks, pyrites, and other metallic objects are usually segregated from the coal at the pulverizer. These materials are also added to the ash handling system installation.

In coal-fired power plants, the quantity of ash generated is a function of the type of coal being used. Some coals have a very low ash content on the order of 2 to 4 percent. Such coals are also characterized by high heating values on the order of 36 to 36.7 MJ/kg HHV (15,500 to 15,750 Btu/lb). Conversely, there are coals, or lignites, having high ash content and low heating values. Consequently, burning a coal with high ash content and low heating value generates considerably more ash for a given amount of heat required. This ash must be collected, transported, and disposed of in a proper manner.

For example, a 300-MW unit burning a 32 MJ/kg (13,000 Btu/lb) coal with a 7 percent ash content would produce 15 t/hr of ash. The same unit burning a 20 MJ/kg (8000 Btu/lb) coal with a 7 percent ash content would generate 24 t/hr of ash, or 60 percent more. Therefore, fuel type is a key factor in the selection and design of the ash handling system. Fuel type affects mainly those parameters associated with the sizing of the equipment and the means of transport.

In addition to the quantity of ash, the type of ash also has a bearing on the ash handling equipment. The type (chemical constituents) can affect the distribution of the ash within the boiler and its auxiliaries as well as the means of transport. Coals with low ash fusion temperatures, usually referred to as slagging coals, will deposit a greater amount of ash in the furnace and subsequently produce a greater amount of bottom ash. Coals with high calcium and magnesium ash can cause pipe scaling

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problems. In addition, they are cementitious and thereby solidify in collection equipment.

5.2 HISTORY OF ASH COLLECTION PRACTICES IN NORTH AMERICA

At the outset, it is necessary to clarify the meaning of the terms "wet" and "dry" often used in the context of ash handling systems. These terms are used to define the ultimate disposal methods and do not necessarily refer to the collection system. For example, bottom ash is often collected in a wet system, but it can be dewatered and mixed with fly ash and transported dry for ultimate disposal.

In the United States, the ash handling systems are typically designed for intermittent operation, usually once per shift, allowing time for maintenance between operations. In other Western countries, particularly where lower grade coals with high ash content are burned, the systems are designed for continuous removal.

There are three major transport system options for disposal: wet impoundment, dry impoundment, and off-site ash transport. These options have been site and end-use dependent. The type of transport utilized is dependent on the disposal option.

Wet impoundment of ash was common in North America until the 1970's when environmental regulations presented problems to this method of disposal. With this type of system, the ash is hydraulically sluiced to the wet impoundment.

The numerous variations on this system are listed below:

- All ash is sluiced to a water impoundment with no water recovery.
- All ash is sluiced and the transport water is recycled.
- Some of the bottom ash and/or the fly ash is collected dry in bins for off-site disposal, with the remainder of the ash going to a wet impoundment.
- All of the ash is collected dry and transported by truck to a dry impoundment. The term "dry" is a relative one because there is water in the ash.

The more common method of disposal since the 1970's has been dry impoundment. Again, a number of variations occur as follows:

- Dry transport of all ash either by truck or conveyor.
- Hydraulic sluicing of the ash with drain collection and recycling of the transport water.

- Pneumatic conveyance of the ash to the disposal area. Both dense and dilute-phase systems are economically limited to distances of about 500 meters because of the high transport velocities required for longer distances. Typically, a velocity of 1800 m/min. is required for a 500m long transport.

Off-site disposal, the final option, always uses a dry transport system with storage hoppers or bins for temporary ash storage, awaiting transport off site by either truck or rail.

Figures 5-1 through 5-4* show the statistical distribution of ash handling system uses as functions of boiler type, boiler size, fuel type and coal type.

5.3 BOTTOM ASH HANDLING

Bottom ash is a slag or deposit that builds up primarily on the surfaces of the furnace and also on the superheater when located within the furnace. It eventually falls by its own weight, by load changes, or by sootblowing into the furnace bottom hopper.

Up until 1980, virtually all bottom ash systems in North America used a water impounded hopper with hydraulic transportation to disposal. This method was universally true with utility boilers. Figure 5-5 shows a typical wet bottom ash hopper. Figure 5-6 is a schematic representation of a water-impounded bottom ash collection system.

Starting in the 1980's, drag conveyors appeared on the North American continent but largely in applications involving non-slagging ash. An example of this application is the fluid bed boilers that became common in the late 1980's.

In the early 1980's, the submerged chain conveyor (SCC) (see Figures 5-7 and 5-8) began to replace water impounded hoppers and sluicing systems for bottom ash collection in new and retrofitted installations. However, during that period, there was also a large decline in the number of pulverized coal-fired boilers constructed, so the benefits of this change may be yet to be confirmed.

To gain some perspective on the reasons leading up to this change, a look at the factors immediately preceding this period is helpful. Prior to the Clean Air legislation of the 1970's in the United States, most of the power generated by coal-fired plants using Eastern United States coal. Much of these coals have a high sulfur

* All figures for this section have been placed at the end of the text.

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content and tendency for slagging (i.e., have low ash fusion temperatures). These coals produce a very fluid ash in the furnace that tends to flow into the ash collection hopper. When the ash does not flow and adheres to the furnace walls (and this is more the rule than the exception), it has a tendency to break from the walls and fall in large pieces, called clinkers, into the bottom ash hopper. Many operators believed that the SCC would not be suitable for handling this type of ash. Several elements needed to be considered. A large amount of water was required for quenching. Large pieces of ash occasionally dropped into the hopper. A breaker for these large pieces was needed.

However, several factors combined to increase the interest in SCCs for bottom ash removal. These included:

- An increased number of installations in Europe and other Western countries.
- Longer North American experience time with earlier installations.
- The appearance of the fluid bed boiler on the U.S. power market with its need for continuous ash removal.
- A change in the U.S. coal usage from Eastern to Western coals because of the lower sulfur content of the Western coals.

The switch to Western coals forced a retrofit of the ash handling systems. Boilers designed to burn Eastern coals had to be changed to allow handling the greater amount of ash, typical for Western coals. Because of space limitations imposed by the clearance under the boiler, the continuous removal of ash afforded by the SCC made it a logical choice for retrofit applications. Because of the simultaneous decline in the construction of large coal-fired boilers in North America, a true test of the SCC method of ash removal has not occurred in the North American market. This is not the case in Europe where submerged scraper chains have been the standard for years.

The greatest amount of coal burned in North America is classified as Eastern bituminous coal. Western coals have increased in usage in the last 15 to 20 years, because of their lower sulfur content. The tonnage burned, however, is still considerably less than that of the Eastern coals.

5.3.1 Submerged Chain Conveyor

The SCC holds the same market dominance in Germany and other parts of Europe that the water-impounded sluicing system currently does in North America. This SCC system is used on most types of firing systems, including pulverized coal fired

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dry and wet bottom boilers, crushed brown coal fired boilers, stoker fired boilers, prepared refuse fuel, and municipal solid waste plants. The style of submerged conveyor is adapted to suit the ash characteristics. In the North American utility market, most SCCs employ a water filled upper trough with an exposed lower return trough.

European equipment has evolved from small power boilers to the current large utility installations. In North America, the specifications are more stringent for large boilers. The equipment is designed for higher peak loads and startup with stored ash. The result is more costly installations than their European counterparts.

Ash capacities of the SCC will depend upon furnace size, the method of firing, slagging characteristics of the coal, fineness of pulverized coal, washing of coal, etc. For bituminous coals, 10 to 15 percent of the total ash is typically collected in the furnace bottom, although in many installations bottom ash exceeds 20 percent. Figure 5-9 shows the typical ash distribution within a boiler as a function of coal type. The estimate on lower rank coals is calculated from dust loadings. The peak ash rates on dry bottom furnaces, resulting from soot blowing or load shedding, can be three to four times the normal rates. Experience in firing oil shale and high ash content brown coals with higher specific weight ash show approximately a 30 percent bottom ash collection rate. Figures 5-10a through 5-10c present the distribution of ash collection rates as a function of coal type and unit size.

Water depths in the upper trough of SCCs are normally 1.0 to 1.5 meters. The drive size, based on continuous removal, is specified at chain speeds of up to 6 m/min. SCCs are not normally designed for startup with an ash load. Therefore, the system must be emptied after a shutdown.

The SCC housing is designed to carry stored ash loads while being moved sideways from beneath the boiler for maintenance. It should be noted that modern submerged-chain conveyors do allow maintenance while the boiler is in operation. The water-impounded hoppers have sliding plates immersed in water troughs to create a furnace seal for normal operation and for maintenance.

SCC Improvements

Over the years, improvements have been made in the chain, idlers, and the chain tension stations. Except for units cooled by sea water, the chain has changed from high-tensile mining chain to carburized alloy chain. This alloy has greater abrasion resistance. Through shafts and overhung jack-shaft idlers with water seals have been replaced by mounted overhung idlers. Manually adjusted chain tensioners have been replaced by spring-loaded tensioners.

Normally, 1.25 cm carbon steel trough liners are installed in the upper and incline trough sections, and basalt grouted tiles installed in the lower trough. For extremely abrasive ash (i.e., high silica, slag tap-wet bottom furnaces), basalt or ceramic is also used on the incline portion of the upper trough. In selecting the liners, the erosion factors of various ashes are evaluated and ranked in comparison with sand (silica). SCC scrapers use abrasion-resistant wear surfaces to support the chain system weight. On SCCs with small incline angles, or with ashes which have a tendency to retain water, the inclines wear liner is supplied with chevron-shaped de-watering grooves.

Various styles of cooling-water overflow boxes are used. Small straight-edge weirs, long serrated-edge weirs, and full parallel plate settlers with serrated-edge weirs are used for suspended solid reduction in the overflow from the SCC.

A variety of designs for transition chutes are employed for the connection between the boiler and the SCC. The styles used vary from alloy steel uninsulated metal chutes, suspended from the boiler, to floor-supported water-cooled metal chutes with water cooling in the annulus. Some chutes incorporate hydraulically operated closure flaps to allow on-line maintenance.

SCC Cooling System

The pool of water in the conveyor absorbs the heat from the hot bottom ash fallen from the furnace. This heat is removed by the SCC cooling system. A typical system design is shown in Figure 5-7. The water discharge is routed by flumes to a gravity settler for solids' removal and treatment. From the settlers the water is pumped through heat exchangers and recirculated to the conveyor. In current SCC designs, the cooling water overflow discharges through a parallel plate settler to reduce suspended solids. Treated river water or cooling tower blowdown water may be used as makeup water source.

Concentration of elements such as Cl (1000 mg/1 to 1500 mg/1) and free CO_2 in the cooling water can cause corrosion, and scale may form due to high levels of CaO. The pH level can be controlled by the manual addition of caustic, and cathodic protection can be provided, either by simple anodes properly placed or by impressed voltage. Generally, the pH level will stabilize in the range of 7.5 to 9.0 without chemical treatment.

At the end of the SCC, the ash is sized by a stationary grate and then crushed to a suitable size for conveyance. Economizer ash can be sluiced into the SCC but, in most cases, the economizer ash is kept separate from the SCC system. After sizing, the ash is conveyed to temporary storage silos in preparation for offsite transportation or is sluiced to on-site impoundment. The conveying means and the location of the final disposal will determine the size of the silos and transfer structures.

Economic Benefits of the SCC

The SCC continuous removal system can provide economic benefits over a water pool hopper with intermittent sluice. A recent study for a lignite-fired 690 MW boiler compared the cost of an SCC arrangement, utilizing a 2.5-meter water depth and 4.5-meter boiler clearance, with a 10.5-meter boiler clearance for a water-impounded system. The SCC system was found to be less expensive because of the following elements:

- Lower building height
- Smaller foundations
- Reduced platforming
- Lower erection costs
- Reduced amounts of ash in storage
- Reduced water inventory
- Improved furnace access during shutdown

The water volume of the water-impounded hopper was approximately 475 m^3 or four times the volume in the SCC. The ash storage of the water-impounded hopper was 14 hours, whereas the SCC has 4 hours of storage. The foundation requirements were less for the SCC because of reduced water, ash, and hopper weights. Operator attention during sluicing periods was approximately 2 hours out of the 8 required to empty the water-impounded hopper, whereas the SCC is operating continuously and requires only a periodic inspection by the operator.

Figures 5-11a though 5-11c show SCC closed-loop cooling water requirements as functions of plant size. Figures 5-12a through 5-12c show the operating kilowatts also as functions of plant size.

Table 5-1 is a list of recently installed SCCs in North America by one manufacturer.

Table 5-1
LIST OF SUBMERGED SCRAPER CONVEYOR CONTRACTS

Company	No. of Units	Boiler Capacity	SCC Maximum Discharge Capacity (t/h)
Southwestern Public Service Roy Tolk Station	Two (2)	520 MW	45
Electric Generating Authority of Thailand - Mah-Moh Station	Four (4)	150 MW	44
Alton Packaging Corporation	One (1)	350,000 lb/hr	6.6
Alberta Power Company - Battle River No. 4	One (1)	150 MW	21
Container Corporation	One (1)	700,000 lb/hr	15
Electricity Supply Commission (South Africa)	Six (6)	600 MW	125
A.E. Staley Mfg. Company, Decatur, IL	Three (3)	125,000 lb/hr	5.6
City of Edmonton - Genesee Station	Two (2)	400 MW	55
Lower Colorado River Authority Fayette No. 3	One (1)	450 MW	100
Eastman Kodak, Rochester, NY	One (1)	550,000 lb/hr	4
National Thermal Power Corp. Uttar Pradesh India	Two (2)	500 MW	
Israel Electric	Two (2)	550 MW	40
China Steel Corporation	Three (3)	440,000 lb/hr	5
Franco Tosi for Bophuthatswana	One (1)	60 MW	10
Connecticut Resource - Recovery Authority	Three (3)	230,000 lb/hr	9
Honolulu Resource - Recovery Authority	Two (2)	245,000 lb/hr	9
Electric Generating Authority of Thailand Mah-Moh Station	Two (2)	300 MW	32
CPS of San Antonio - J.K. Spruce Station	One (1)	520 MW	45
Old Dominion Elec. Co. - Clover Station	Two (2)	400 MW	30
Tex-Mex - CFS Unit	Two (2)	80 MW	30

5.3.2 Dry Bottom Ash Conveyor

A new system for handling bottom ash has become available in Europe and recently in the United States. This new system was installed on several boilers, some as large as 575 MW. The system uses a dry conveyor cooled by air. By utilizing air instead of water, the ash is handled completely in the dry state, which offers many advantages over a wet system.

The system uses a fully enclosed, stainless steel conveyor that continuously removes bottom ash. The ash is transported to a primary crusher where it is crushed and collected in a tank. From the tank, it is pneumatically conveyed either by pressure or vacuum to a collection silo where it can be disposed of either off site or on site by truck. See Figures 5-13 and 5-14.

Conveyor Housing

The conveyor housing contains air ports, which can be adjusted, that allow air to enter. The air cools the ash and the conveyor, and exits to the boiler through the furnace bottom opening. The air amounts to 0.5 to 1.0 percent of the boiler's combustion air requirement. The combustion air is reduced accordingly. The ash exits the conveyor at a temperature of approximately 135°C.

Hydraulically operated doors are used to isolate the furnace bottom hopper such that maintenance can be performed on the conveyor. Typically, 8 hours of storage are provided in the hopper for the maintenance work to be done.

The belt is a stainless steel mesh covered with stainless steel plates, fastened with rivets and arranged to form a continuous plate. The mesh is supported on steel rollers along the forward and return runs and guided around steel drums at each end (see Figure 5-15). One drum is the drive wheel and the other maintains tension on the belt. Rollers and drums have exterior supports and bearings, isolated from the heat within, and can be changed from outside the unit without dismantling the unit. The belt speed is in the order of 15 to 18 m/min.

Because the ash is not quenched in water, it can continue to burn on the conveyor as it is being transported, thereby reducing the unburned carbon in the ash and allowing this heat to return to the boiler. This produces two desirable results, one is an increase in boiler efficiency and the second, is an ash that is more suitable for use in cement making. By screening, different size products may be obtained and sold for various end uses such as cement production. Since the system uses no water, impoundment is simplified and transport costs are reduced.

Plant Efficiency

An increase in plant efficiency is realized because:

- No heat is lost to water in the conveying system.
- No pumping power is used for supplying water to the collection system
- The water does not have to be purnped as part of the transport system and
- Water does not have to be pumped back in the reclaim system.

The system eliminates settling ponds; therefore, there is no ash contaminated water. This eliminates problems concerning environmental regulations. Other advantages are no water treatment chemicals or equipment and elimination of water freezing problems in cold climates.

In addition, there is no auxiliary cooling water system requiring piping, pumps, or heat exchangers. This, of course, eliminates corrosion, erosion, and scaling problems.

Figure 5-16 depicts the amount of unburned carbon in bottom ash for various coals and for wet and dry collection systems. It is this carbon that accounts for losses in the furnace and makes the ash unsuitable for cement making purposes. Figure 5-17 compares the sources of various losses between the dry and wet collection systems.

Figure 5-18 shows a typical dry ash conveyor with a mechanical handling system, while Figure 5-19 shows the same system with a pneumatic handling system. Plant specific factors and economic considerations govern the implementation of one system over the other.

Figure 5-20 shows the materials balance for a dry and a wet system for a 4 x 300 MWe plant. This arrangement was used for an economic study that resulted in the payback period being as short as 1.7 years.

A study performed for a U.S. utility generating 5 t/h of bottom ash compared a wet hopper with hydraulic sluicing to a de-watering bin. In addition, trucking to an on-site impoundment with a dry ash conveyor showed a net saving in operating costs of U.S. $ 1.1 million for 1 year.

5.4 PULVERIZER (MILL) REJECTS

5.4.1 Historic Practice

Pulverizer rejects consist of pyrites and tramp iron or other materials too heavy to be conveyed by the pulverized coal transport air or too large to pass through the mill classifier. This material is collected in a hopper located at the bottom of the pulverizer.

In some plants where the amount of rejects is extremely small, the hopper contents are collected manually and disposed of with the bottom ash. The more common practice is to collect the material and hydraulically sluice it to some other location in the ash collection systems.

The practice on many of the older plants was to collect the reject material on a sequential basis, and hydraulically sluice, using jet pumps, to the bottom ash hopper. This method was discontinued in favor of providing a jet pump for each pulverizer hopper. This practice allows emptying more than one hopper at a time, and discharging into a collection tank.

The discharge of the material directly into the bottom ash hopper was discontinued when it was found that the mater splashing onto the lower furnace tubes was causing stress corrosion cracking. With an SCC, it is possible to introduce mill rejects outside the water seal plates eliminating the problem. This is also true for the dry bottom ash conveyor.

5.4.2 Current Practice

Today, a system designed for a lignitic or subbituminous coal would have individual jet pumps for each hopper and hydraulically sluice the material to a transfer tank for a water impounded bottom ash hopper system. In the case of a mechanical conveyor bottom ash system, the material would be sluiced to the chain conveyor at a point outside the furnace bottom ash transition chute (see Figure 5-21). If the mechanical chain conveyor were not to discharge to a second removal conveyor, but instead hydraulically sluice the material to disposal, the reject material could be discharged at this point instead of onto the chain conveyor.

Mill rejects gathered by the dry collection and transport systems are conveyed by either pneumatic or mechanical means. The amount of material and the distance transported would dictate the choice.

5.5 ECONOMIZER ASH

The particle size of economizer ash is somewhere between bottom ash and fly ash. It is a high-temperature (usually over 370°C) coarse ash and can contain combustible material. It may have the physical characteristics of hygroscopic fly ash. Economizer ash is collected in a row of hoppers beneath the boiler economizer section. When stored in these hoppers and exposed to in-leaking air, the ash may sinter and agglomerate, making it impossible for it to flow.

In North America, the practice is to remove the economizer ash continuously, in a method analogous to the continuous removal of bottom ash, so as to cool it and prevent combustion of any residual unburned carbon. For bituminous coals, water-filled tanks are used beneath each economizer-hopper outlet. The ash is stored in these tanks, for intermittent removal by hydraulic eductors, rather than in the economizer hoppers (see Figure 5-22.)

The wet collection method is not practical with ash from burning lignite or subbituminous coal that contains a high percentage of calcium. Such ash shows pozzolanic and cementitious properties when mixed with water, and requires frequent evacuation from the wet tanks to avoid the possibility of plugging. Some utilities burning cementitious coals have used dry transfer tanks below the economizer hoppers achieving the desired continuous removal without tank or line plugging problems.

The lack of an effective economizer hopper evacuation system can result in excessive ash loadings in the hopper. High loadings have caused structural failures of hoppers in North American operations. Economizer hoppers are designed for a full load of ash, but incidents of failure have occurred when large quantities of ash were deposited above the top of a full hopper. In these instances, the hopper support system failed, and the hopper dropped on the air heater below. Hopper evacuation systems must be designed with sufficient removal capacity so that overloading does not occur.

During boiler startup, when pulverizer classifiers are not yet set or combustion air dampers may not be in their optimum positions, ash from the rear-pass can contain high percentages of carbon. When exposed to temperatures above 340°C to 370°C and leaking air, the carbon will burn slowly. If the ash is not evacuated from the hoppers continuously, it becomes so compacted that it cannot flow out of a 200 mm or even 300 mm diameter opening which is the usual size of that opening.

In some installations, a solution to this problem has been attempted by the addition of small clinker grinders below the economizer-hopper outlets. A better solution is to enlarge the hopper opening to between 400 mm and 450 mm in diameter and put an ash-receiving tank, dry or wet, depending upon the calcium content of the ash, below the hoppers to get the ash out of the boiler gas stream as expeditiously as possible. In a design such as this with receiving tanks below, the hoppers have essentially zero holdup time and act only as chutes.

5.5.1 Air-Heater Problems from Plugged Economizer Hoppers

When firing high-calcium subbituminous coal, and using water-impounded tanks to continuously collect the ash from the economizer hoppers, the ash depositing in the wet tanks can coalesce and the tanks can become full of concrete. Also, the moisture evaporating from the surface of the water in the tanks can react with the falling ash and cause plugging of the down-spouts in the economizer hoppers. In such cases, the ash is carried along with the flue gas stream to the air preheaters and is deposited on the surfaces, causing blockage of the air-heater gas passages. This results in an increase in the gas-side draft loss. There are cases where this has doubled the normal draft loss. Refer to Figure 5-23 for configuration.

Regenerative Air Heater Fouling

The usual mechanism of regenerative air heater fouling is by two means. Acid condensation on the plates caused by sulfur in the coal and ambient temperature below the acid dew-point temperature. The acid combining with the ash forms a solid mass that occludes the spaces between the baskets' plates. The second mechanism is one in which larger ash particles become lodged between the plates, accumulate, and then have the smaller particles begin to fill the gaps between the plates eventually causing complete blockage of a path.

Air-heater blockage is not unusual, particularly when burning high-calcium coals (above 15 to 20 percent CaO+MgO in the ash). Since the plugging greatly increases both the total gas draft loss and the air-side pressure drop of the air heater, the boiler no longer can carry full load. When this fouling becomes severe enough to cause an excessive pressure drop across the air heater the boiler must be tripped for cleaning. Clearing of such plugging calls for severe cleaning procedures, generally a high-pressure water jet wash.

Gas Flow Field and Ash Particles Trajectories

Recently, methods have been developed and utilized on a number of power plants to define the gas flow field in the hopper region and predict the ash particles' trajectories. The goal is to capture a greater percentage of particles in the economizer hoppers. The objective is to minimize the number of larger particles (500 microns or greater) going to the air heater and causing blockage. On units where this numerical simulation has been applied and corrective measures applied, the capture rate of 500 microns and larger particles improved by 10 to 24 percent.

Corrective procedures involve the addition of baffles in the gas stream and plates to prevent rebounding of particles already in the hopper area. Of course, the capacity of the economizer ash handling system must be evaluated to determine its adequacy.

5.6 FLY ASH

The fly ash system collects the largest amount of ash and also accounts for the majority of problems in ash collecting systems.

Electrostatic precipitators, used for the collection of fly ash from steam generators, are mostly of the dry, horizontal-flow, plate type (Figure 5.24). The flue gas flows through parallel passages formed by parallel rows of collecting surfaces. Each passage contains centrally located discharge electrodes, which are energized with negative-polarity, high-voltage, direct-current electricity. Particles suspended in the gas are charged electrically and then forced to the collecting electrodes by an electrical field.

During operation, the fly ash deposited on the collecting surfaces of the precipitator is periodically shaken loose (by rapping the electrodes) and dropped into the collection hoppers. The level of ash in each hopper will rise until that hopper is emptied. If, for any reason, emptying the hopper is delayed until the ash level approaches the bottom of the discharge electrodes, those electrodes will be electrically short-circuited to ground through the mass of collected ash.

If the ash and flue gas entering the precipitator are well distributed, all precipitator hoppers in any row perpendicular to the gas flow will collect the same quantity of ash per unit time. More fly ash will be collected in the rows of hoppers closer to the precipitator inlet than in the rows toward the rear of the precipitator. The inlet row of hoppers can collect from 40 to 100 times as much fly ash as does the rearmost row.

Boilers burning high volatile subbituminous and lignitic coals, with a high percentage of calcium oxide and magnesium oxide in their ash, produce ash that is made up of small particles. The small particle size contributes to compaction in the hoppers, while the high calcium content can lead to the rapid formation of fly ash concrete in hoppers that are contacted by moisture.

Most pulverized-coal fly ash is hygroscopic. In the hopper outlets, the ash particles are surrounded by stagnant flue gas. On startup, shutdown, at low boiler loads, or during the ash-removal process, the local gas temperature in the hoppers can be below the acid dew-point (120-150°C) or below the water dew-point (approximately 55-60°C). Under such conditions, in which acid or water is produced by condensation, agglomeration and/or cementing of the particles can take place, resulting in hopper plugging and the inability to remove the collected ash from the hoppers.

5.6.1 Fly Ash Systems

The conventional practice in North America is to remove fly ash from precipitator hoppers on an intermittent basis. To reduce the amount of power required for ash handling, fly ash removal systems are sized to collect ash for long periods between hopper emptying.

In the West, the types of collection systems most commonly used are:

- Combination vacuum and pressure conveyor
- Hydraulic vacuum conveyor
- Pneumatic vacuum conveyor
- Pneumatic pressure conveyer (dilute and dense-phase)

Combination Vacuum and Pressure Conveyor

A combination vacuum and pressure conveyor system is shown in Figure 5-25. This arrangement is used where there are a large number of precipitator hoppers and the fly ash is conveyed to a remote silo. This system offers the economy of the vacuum fly ash intakes under the hoppers and the pressure system for long distance transportation.

An important alternative method to the pressure systems, shown in Figure 5-26, is to pressure convey the fly ash to a local storage pond. The fly ash is moved dry and water sprays (wetting heads) are injected into the pipeline discharge at the pond for dust control.

For all of the above systems that include silos, rotary wet unloaders are utilized for mobile transport of the ash to a fill area. If the dry fly ash is to be sold and transported off site, then discharge spouts to covered mobile vehicles are used.

Hydraulic Vacuum Conveyor System

In a hydraulic vacuum conveyor system, the fly ash is vacuum conveyed to a dry fly ash silo, or alternately, wet sluiced to a fill area as shown on Figure 5-27. Many recently installed units utilize this type of wet fly ash-handling system because of the simplicity of operation, and both the bottom ash and fly ash can be discharged to the impoundment area through common pipelines. This method also has the advantage of utilizing a common high-pressure sluice water pump for both the bottom and fly ash conveyor systems.

This hydraulic vacuum arrangement has applications where ash volumes are small and the water supply is plentiful. However, most new units would not meet current U.S. EPA effluent regulations with this type of system. In addition, this system would not be applicable for plants burning the typical low-sulfur U.S. Western coals with high calcium oxide where plugging problems can occur.

Dry fly ash silos, which sluice to fill areas, can be retrofitted to meet environmental requirements or to market fly ash. Figure 5-25 shows how these existing installations can be retrofitted.

Pneumatic Vacuum Conveyor

Figure 5-25 also presents a method of pneumatically conveying fly ash with vacuum created by mechanical exhausters. At the top of the surge transfer silo, the fly ash is removed from the air stream by various stages of separating equipment and dropped into the silo. The last stage of separation, usually a bag filter, collects any remaining ash, which would tend to wear out the exhausters. The system is simple; however, it is limited by the vacuum pressure (approximately 458 mm Hg), temperature (which may preclude its use with a hot precipitator), elevation, and the proximity (within approximately 250 m) of the ash silos.

Pressure Conveyor (Dilute and Dense-Phase)

For higher ash-handling capacities, or to transport fly ash a longer distance to storage, a pressure conveyor system, as shown in Figure 5-26 can be used. The higher capacities are achieved through the use of 2.6 bar and higher operating pressures. This system empties more hoppers at a time, as opposed to individual hoppers with the vacuum system. Another advantage is that the blower handles clean air. The pressure system hardware (especially air-lock feeders) is more costly and becomes a major consideration when large numbers of hoppers are involved.

In pressure systems, an air-lock feeder transfers fly ash from the hoppers at low pressure to a transport pipeline at a higher pressure. Compressors or blowers provide the airflow and pressure to convey the ash. All such systems presently in operation in North American power plants are of the dilute-phase type. Dense-phase systems are used extensively in other industries and a great deal of experience is available.

Pneumatic ash-removal systems are not designed to handle wet material. It is necessary in the operation of hopper systems to maintain collected material temperature sufficiently higher than the water or acid dew-point to keep it dry, so that it will be free-flowing.

Dry ash in hoppers ordinarily will flow freely by gravity and can be transported pneumatically without difficulty. To do this, the dry ash

- must be kept at the temperature at which it was collected
- must not be exposed to moisture
- must not compact from its own weight, causing bridging above the hopper outlet, and
- must not form clinkers as the result of oxidation of combustibles.

Hopper flow problems result from the compaction of the material in the hoppers. The degree of compaction in a hopper is affected by the moisture content of the solid, the size and shape of the particles, the height of the material, and vibration caused by external plant equipment. Compaction in a gravity-flow hopper will manifest itself as arching and "rat-holing." Externally mounted hopper vibrators, if operated incorrectly, will increase compaction and worsen the problem.

It is frequently difficult to maintain the ash freely flowing if it has been stored after exposure to flue gases containing moisture and sulfur. Therefore, the storage of ash in collection hoppers should be avoided.

Continuous removal of fly ash from precipitator fly ash outlets can help to reduce power consumption. However, the primary purpose of continuously removing fly ash from precipitator hoppers is to avoid shorting of precipitator plates by accumulated ash. Whatever type of continuous removal equipment is used, it should provide for continual emptying of hoppers without significant residence time to avoid cooling and subsequent plugging problems.

Mechanical flight conveyors have been successfully used in Europe for the continuous removal of fly ash from precipitator hoppers. Such devices have the return run above the carrying run, with the conveying elements confined in a totally enclosed casing to minimize the possibility of air infiltration. The flights are not in contact with the bottom of the trough, which eliminates wear of the trough floor.

Figure 5-27 is a conceptual arrangement of such equipment, combined with a conventional pneumatic conveying system.

5.6.2 Pneumatic Fly Ash Removal Systems

Vacuum systems use mechanical blowers, water or steam exhausters to create a vacuum that removes the fly ash from the hoppers (Figure 5-28). A fly ash intake valve located at each hopper regulates the flow of the fly ash. Fly ash intake valves have carbon steel or cast iron bodies and a swing disc that seals against a hardened seat. For maintenance, the outlet of each hopper has a manual isolation gate.

In some types of systems, this valve is fully opened or closed on a signal from the downstream vacuum switches. This ensures that the fly ash will leave the hopper at the proper flow rate and that excessive ash will not flow from the hopper and plug the discharge line. The air is provided to the system through check valves located at the inlet of each branch of hoppers.

The positive-pressure dilute-phase system connects to each hopper using an airlock type feeder (Figure 5-29). Theoretically, due to its cycle of operation, the positive pressure is never communicated to the hopper. Practically, this is not true; the feeder can be considered as a chamber separated from the hopper by an inlet gate and from the conveying line by a discharge gate. The chamber is alternatively pressurized to conveying line pressure or vented to hopper pressure or less to allow the chamber to be emptied or filled. Although there are several modes of operation, the above can take place on a 2-minute cycle and continuously. To obtain a continuous flow of material into the conveying line, a minimum of two feeders working in sequence must be maintained.

There are two commonly used types of intakes: the first (Figure 5-30) uses a disc-type gate between the intake and conveying line; full-load control is accomplished by opening and closing the gate with full conveying air flow supplied through an air intake in each conveying line. The second type (Figure 5-31) introduces most of the conveying air either through the intake itself or from the hopper above. This type of intake, which in effect is a 90-degree elbow, isolates the hopper from the conveying line by virtue of its shutoff gate being in the horizontal line. The air intake at the end of the conveying line is normally restricted and requires a fairly large pressure drop to admit full conveying air. A scavenger valve, located downstream of the ash intakes and before any riser, is used for full-load regulation. With both types of intake, after the initial discharge of material from a hopper, almost all the conveying air or gas comes from the hopper and not from an outside source.

5.6.3 Vacuum System Controls

Negative-pressure pneumatic conveying systems can have several different types of material intakes, various combinations of separating equipment, and different types of exhausters. As a result, there is no single control system for all applications.

The majority of vacuum systems use full-load control, whether by valves using a scavenger valve or the method employing opening and closing of the fly ash intakes. Each provides equal results. "Full load" is defined as the system design vacuum measured at the inlet to the vacuum producer.

When a hopper is empty of all material, the system vacuum drops to a level approaching that of air flow alone. A no-load vacuum switch is set to close between no load and full load vacuum and is used to energize the transfer mechanism. The contacts of the no-load vacuum switch are in series with a time-delay relay. When the no-load vacuum remains for a time, the sequence switch is energized which transfers operation from one hopper to the next. The sequence switch also controls the branch line gates and the water supply valve. The use of the time-delay prevents transfers due to momentary low-vacuum readings.

Power (vacuum), for system operation, is produced by a water exhauster or by a mechanical blower. To create the cycling effect, both the material intake and the airflow are cycled constantly. A vacuum breaker alternately open and closed to the atmosphere is used to cycle the airflow.

No-load vacuum is defined as a vacuum at or above an empty-line vacuum to and below full-load vacuum. The total operating time of a system can vary greatly; it depends on how well the material is feeding from the hopper and the value at which the no-load switch is set. When a hopper is emptied to where full-load vacuum cannot be achieved, it is considered empty. When a system consists of several branch lines, especially with branch lines far apart, more than one full-load or no-load switch is necessary. The full-load vacuum, the length of the line and the material temperature, will determine capacity from one location to another in the system.

5.6.4 Positive-Pressure System Control

A positive-pressure conveying system can have many configurations. Although there is no theoretical limit to the pressure at which they can operate, 10 to 12 bar (for dense-phase conveying) is the practical limit for most systems.

An airlock feeder is required to introduce fly ash into the conveying line.

Dilute-Phase, Positive-Pressure Systems

Dilute-phase, positive-pressure feeders containing a single compartment airlock, isolated by inlet and outlet valves, are the type commonly used in utility ash systems. They can be charged with material or they can discharge material, but do not do both simultaneously. To obtain a continuous flow of material into the conveying line, two or more feeders are operated on offset cycles. Two methods of discharging dilute-phase air-lock feeders are commonly used.

In the first method, one-half of the total number of feeders in one branch line discharges material to the conveying line. During this time the other feeders are in the process of venting, filling and pressurizing. Each feeder operates on a cycle of about two minutes and is continuous until all the material stored in the hoppers has been discharged. When this occurs, the operating pressure drops to a no-load value. A no-load pressure switch, in series with a time-delay transfers operation to the next branch line or to shutdown.

In the second mode, only one feeder per branch line is active at any one time. A second feeder is vented, filled and pressurized just prior to the end of the active feeder's cycle. The bottom gate of the active feeder closes and that of the second feeder opens. Operation continues in this manner until each feeder of the branch line has operated a set number of times. When this occurs, operation is transferred to the next branch line or to shutdown.

For a feeder to receive material, it is at a pressure equal to or less than the hopper to which it is connected. This is accomplished by a vent system that allows the air in the feeder compartment and the displaced air from the incoming material to be vented.

For a feeder to discharge material, its chamber is at a pressure equal to or slightly higher than the conveying line. This is accomplished by supplying air from the blower discharge to each feeder on a controlled cycle.

With dilute-phase pressure systems, a full-load pressure switch, located at the discharge of the blower, is used to regulate the amount of material in the conveying line so that it does not exceed system design. When the full-load pressure setting is reached, all open lower gates are closed until the operating pressure drops below design.

Dense-Phase, Positive-Pressure Systems

Dense-phase, positive-pressure pneumatic transport systems use the same hardware as described for dilute-phase systems. A significant difference in the mode of operation is that the air-lock feeders are kept open in the receiving position whenever they do not contain ash up to the desired level of accumulation. In the open position, the air-lock becomes an extension of the hopper under which it is mounted.

Comparisons between dilute and dense-phase systems indicate a lower capital, operating and maintenance cost associated with the dense-phase system. The levelized costs being about 10 percent less. Notwithstanding, the dilute system continues to be the choice of Western utilities.

Dense-phase conveyance of ash is used in other industries and on industrial boilers and in time will probably be used for utility boilers. The dense-phase requires less air to move a comparable amount of material. Because a lesser quantity of air is required for a given amount of material transported, power consumption is reduced, the velocities in the system are lower and the distance that material can be transported, without booster stations, is greater. In this way, it is more economical in operation even though the initial installed costs are higher.

Dense-phase transport can be used in conjunction with dilute-phase systems, air slides, mechanical conveyors, and vacuum collector systems.

The lower transport velocity produces less abrasion in the piping system and allows the use of more common piping materials. Some manufactures of this equipment claim transport distances of up to 1.5 km by the use of booster fittings. These fittings inject small quantities of air along the transport pipe at locations where friction increases such as at an elbow. These fittings allow air to be introduced at points in the line where it can most effectively be used, rather than at one point such as the blow tank where usually too much air is injected. One installation of interest utilized continuous removal air slides discharging to a dense-phase transporter which in turn conveyed the material to a storage silo for ultimate disposal.

Dense-phase transport systems show much promise for future ash collection uses because of the economies of operation and the longer expected life for the transport piping.

5.6.5 Basic Hopper Design

In 1980, a joint paper was presented by an ABMA/IGCTCommittee (Joint Technical Committee of the American Boiler Manufacturers Association and the Industrial Gas Cleaning Institute, Inc. on precipitator Hopper Operations).

The hopper as it is installed on a precipitator (Figure 5-32) is triangular in cross-section, with sides of 60 degrees or higher to the horizontal, with valley angles of 50 degrees or higher. It is usually insulated from the neck above the discharge flange, with the insulation covering the entire hopper area. The lower one-quarter to one-third of the hopper wall is heated.

The ABMA/IGCT Committee recommended that there be no specified storage time in collecting hoppers. When a high hopper ash level is indicated, the precipitator field(s) over that hopper should be shut off.

The ABMA/IGCT Report suggests that the following hopper hardware and auxiliaries be considered in the design:

1) Hopper vibrators, to be used to eliminate bridging and rat-holing, but not with damp ash where their use may compact the ash. With automatic operation, vibrators are to be operated only with the conveying system in operation.
2) Fly ash fluidizers, which have porous membranes that uniformly distribute airflow through the material above, filling voids between particles and changing the angle of repose of the material. This promotes gravity flow. Fluidizing devices assist in hopper emptying, provided they are supplied with dry air above the dew-point, and delivered to the fluidizers without a drop in temperature. Fluidizers can aggravate evacuation problems by caking the ash and providing additional surface area for ash accumulation if the air is not dry. Where high percentages of combustibles are present in the collected fly ash, the gas supply to the fluidizers must be non-oxidizing to prevent hopper fires.

Fluidizers establish an effective discharge diameter large enough so that ratholes or arches cannot form. This diameter is different for each hopper and material. The effective area of a fluidizer is directly (vertically) above the fluidizing membrane (Figure 5-33). For material outside that area, flow must be induced by gravity which results in funnel flow pattern. In a conical hopper, there is virtually nothing to stop this type of flow once established, whereas in a rectangular or square section hopper, this flow can be affected by compaction in the valleys.

There are precautions to be taken when initial firing with pulverized coal. Condensation may form because of low hopper temperatures present during the startup of a boiler. To prevent this, the following precautions should be observed:

- Initiate hopper heating in advance of fuel firing.
- Place the steam or hot-water air duct heater in operation ahead of the boiler air heater at as high a temperature as possible.
- Advance temperature rapidly and operate above 15°C whenever possible
- Operate fluidizing devices supplied with heated air.

During boiler shutdown, the ash system should be operated to clean all material from the hoppers and ensure that hopper walls are dry.

Recent U.S. Design Developments

Since the publication of the ABMA/IGCI Joint Committee in 1980, there have been relatively few fly ash removal systems specified and purchased in the United States, due to the small number of utility steam generators purchased. Several existing boilers have been converted to coal firing and retrofits of particulate-collection equipment have also taken place. In these projects, there has been interest in following the recommendations.

Since the report, one utility has specified continuous (mechanical) removal systems on a large number of new precipitators, as well as retrofitting older equipment with similar systems.

One U.S. utility has specified a pneumatic fly ash-removal system that is considered to be of a most advanced design, adhering to the committee recommendations. The utility is attempting to improve the availability of its pneumatic fly ash removal systems so that precipitator equipment downtime is minimized. In this system, fly ash handling is divided into two separate systems:

- **Fly ash collection system:** to remove ash by vacuum from the precipitator and air heater for transports to the transfer silo

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- **Fly ash transport system:** to take the ash from the transfer silos and convey it to ash storage silos for loading into mobile equipment.

The maximum continuous fly ash production is expected to be 128 tons per hour. The fly ash collection system is designed to collect 300 tons per hour, and the transport system, to transport 240 tons per hour.

The fly ash collection system must remove sufficient material from 8 air preheater and 60 precipitator hoppers such that ash buildup will not interfere with operation. It uses a vacuum system for removal of the fly ash from the air heater and precipitator hoppers, with transport to an intermediate transfer silo. From the transfer silo, a positive-pressure pneumatic system conveys the ash to disposal.

The vacuum system was selected for the following reasons:

- Lower cost than airlock feeders required for a pressure system.
- Lower maintenance cost because of the reduction of 50 percent of the fly ash valves.
- Positive removal from hoppers by vacuum and of gravity instead of gravity only.
- Less height required with vacuum system hardware.
- Automatic vibration of hoppers is feasible.
- External indication of the interior hopper conditions is possible.
- Lower reverse flow through worn intake valves because of the low differential pressure across the valves (on the order of 50 to 75 cm H_20 instead of 1 to 2 bar with a dilute-phase pressure system or 3 to 7 bar with a dense-phase system).
- No venting of air-lock feeders is required.
- Removal time is optimized. With a pressure system, removal of ash is determined by level indicators and/or timers, because of the airlocks' finite size.

The system has six separate, simultaneously operating vacuum branches, allowing for a continuously operating system. Each vacuum header has a design capacity of 50 tonnes per hour each. The vacuum is produced by mechanical vacuum pumps.

A disadvantage of vacuum systems is that airleaks cannot be easily detected. Conversely, with positive-pressure airlock feeders, leakage of air into the hoppers can be high. A properly erected and tested vacuum system will have minimum inleakage. In pressurized systems, greater damage is done by high-pressure air leaking across fly ash intake valve seats than by the leaking in a vacuum system.

The system is designed for six hoppers to be emptied simultaneously. Vacuum to pressure transfer takes place at two separate transfer silos. These transfer locations are within 150m of the most distant precipitator hopper, and are capable of independent operation.

Each precipitator and air preheater outlet has a manually operated slide gate valve and a pneumatically operated hopper outlet valve. Swing gate valves for hopper application have knife-edge replaceable metal seats, with provisions for access, cleanout and disc replacement without removing the valve body. The shut-off slide gates are installed so that all apparatus can be removed for maintenance. Each pneumatically operated valve has a proximity type limit switch at each extreme of travel, to indicate "fully open," or "fully closed" valve position.

Means are provided to continuously fluidize the ash in all hoppers. The fluidizing system is intended to keep the collected ash in a non-compacted state, drive off the high moisture flue gas, and supplement the heating provided by the hopper heaters. To facilitate ash removal, the blowers supply hot (140°C) dry air for fluidizing in the hoppers. The system has sufficient air capacity to empty six hoppers simultaneously. All hoppers and fluidizing air piping are insulated.

The trend in North America is to dry transport and disposal (impoundment) with off-site removal, for either sale or landfilling. Environmental regulations have also contributed significantly to the choice of dry and off-site disposition of ash.

New Collection Systems

Most current work deals with retrofitting of existing systems. New coal-fired units require flue gas de-sulfurizing which alters the collection of ash, most notably that of fly ash.

Currently, the preferred means of collection employs vacuum collection at the precipitator hopper and short distance conveyance to an intermediate transfer silo. Mechanical blowers are preferred to produce the negative pressure. Cost analyses have demonstrated the economic advantage of using mechanical blowers rather than water or steam exhausters.

For high ash loadings, mechanical conveyors will be utilized to perform the collection and short distance transport functions.

Pneumatic conveyance will have greater use of dense-phase transport due to the favorable economics involved.

Pumping to disposal will use low ash/water ratios to minimize the amount of water in the disposal area. The 1:1 ratio described later will become common.

5.6.6 Fly Ash Removal Systems and the Precipitator

In the latter part of 1974, the TC-1 Committee of the Air Pollution Control Association made a survey of the major users of electrostatic precipitators. Maintenance requirements and problems were investigated. The 174 responses received represented experience with 243 precipitators of various manufacturers, the bulk of which were the "American" weighted-wire discharge-electrode types with an average service life of 7 to 10 years.

The survey reviewed operation and maintenance and detailed specific problems. From the respondents, 36.4 percent indicated that the precipitators had "frequent failures,", 42.0 percent reported "infrequent," and 20.5 percent indicated that the precipitators have "very seldom" failed. Discharge electrode failures, raper/vibrator failures, and collecting-plate failures were documented. The report indicated that 35.2 percent of the problems were with discharge electrodes and 31.8 percent were with dust removal systems. It was assumed that some of the emitting electrode failures were caused by hopper blockage and shorting of high voltage bus sections.

The report stated that, "the removal of ash, once precipitated, has historically been one of the major causes of precipitator malfunction, as well as a contributory factor to other problems such as discharge electrode failure." Ash hopper plugging caused the majority of problems.

Studies have attributed 50 percent of precipitator downtime to problems with ash removal systems. Precipitator malfunction can result in high stack opacity and ash carryover to the induced draft fans, both of which can force a boiler out of service.

Fly ash flows as a liquid above the dew-point, but when cooled below 120°C to 150°C for coal fly ash and 175°C for oil fly ash, its hygroscopic nature causes agglomeration and caking. To avoid problems, fly ash must be maintained above its dew point temperature.

Even if flue gas temperatures are above the dew-point, hopper skin temperatures at the throat area can be lower, because of the heat-sink effect of the ash system hardware and deteriorated insulation. The agglomeration problem can be aggravated by severe weather conditions and exposed hoppers facing a prevailing wind. Condensation, corrosion, and plugging problems are also caused by gas leaks in the hopper, leaks at the inlet and outlet breaching, and the shell.

Flue gas conditioning with sulfur trioxide and ammonia for enhanced precipitator collection can aggravate evacuation problems by producing increased agglomeration of the fly ash.

Electrostatic precipitator maintenance costs may be as high as 10 percent of the installed cost per year, making it economically justifiable to correct hopper blockage.

Hopper plugging may result in the following problems:

- High voltage bus sections can short circuit.
- Collecting and emitting system components can become misaligned which will lower electrical power input.
- Ash fusion caused by high-voltage current can form large clinkers that are difficult to remove and can obstruct a hopper throat.

If a plugged hopper cannot be emptied through the ash system in a normal manner, then the ash must be discharged to the ground and manually removed. The problem can be minimized with the following steps:

- Add heat to the hopper walls, especially at the throat area, to counteract the heat-sink effect of the ash evacuation system. Install thermal insulation between the hopper throat flange and valve assemblies.
- Insulate doors, poke holes, strike pad shafts, and vibrator-mounting plates.
- Install level alarms to prevent precipitator damage from high ash levels. With center hopper dividing baffles, two (2) level indicators are needed since ash can plug one side while the other evacuates normally. With electrostatic precipitators, the first indication of full hoppers is an abnormal decrease in electrical power readings and increased sparking on adjacent high-voltage sets over the plugged hopper(s). If not detected, the electrical voltage will continue to decrease to the point that the primary and secondary voltages will go to zero or nearly zero, depending on the ash quality as an insulator. The transformer primary and secondary currents will return to normal levels after sparking subsides and a short circuit condition is established. The power supply should be turned off automatically before this occurs.

- Use alarms to detect high-voltage grounds and hopper ash levels that have made contact with the high-voltage system. High-voltage current can heat the fly ash to fusion temperatures and form large glass-like clinkers when the ash fills the area between the electrodes. Ash fusion temperatures typically range far higher than the temperature necessary to cause failure of emitting electrodes. In extreme instances, large areas of collecting plates can melt.
- Increase the discharge-valve and associated piping sizes from 200 mm to 300 mm diameter where high dust-collection rates are expected. The increased throat diameter of 300 mm reduces plugging problems.

Low internal temperatures do occur in precipitator hoppers. In one instance reported, internal gas temperatures of 37°C were measured in operating precipitator hoppers while the temperature of flue gas passing over the collecting plates was 150°C, and an outside (ambient) temperature of 25 to 32°C. The rear-end hoppers in a precipitator cool down because of the smaller amounts of ash they collect, and temperature measurements have shown that these hoppers can have essentially ambient temperatures. Leakage of air through the fly ash intake valves at the bottom of the hoppers is also a reason for the low internal hopper temperature.

Fly ash intake valves may open and close nearly 250,000 times per year. Under such conditions, valve seats will wear, resulting in air leakage into the hopper. With a pressure pneumatic system, air can be forced into the hopper at pressures as high as 100 psig (in a dense-phase system). With vacuum systems, the motive force for inducing air into precipitator hoppers is the suction maintained in the precipitator by the induced-draft fans. This suction can create a vacuum of about 50 cm H_20 in the precipitator. With either system, there is a pressure differential that can result in leakage of cool air into precipitator hoppers, leading to condensation of moisture in the flue gas.

A European utility, burning a 40 to 50 percent ash coal for over 25 years, experienced leaky fly ash intake valves that had been worn by the passage of abrasive fly ash. This condition resulted in leakage of air and cooling of the inside of the hoppers. The leaking valves caused the interiors of the hoppers to cool below the water dew-point. This cooling led to flue gas condensation and accumulations of fly ash in the hoppers, causing precipitator electrodes to short circuit. The high calcium fly ash formed large pieces of concrete like material that required manual removal.

5.6.7 Fan Damage from Fly Ash Carryover

There are two categories in this problem area. The first category is the recycle of fly ash that has been collected in a precipitator where the ash is spilled or blown out of the hoppers or the transport system and is re-entrained by the forced draft or primary air fans and carried back to the furnace, damaging the fans in the process. Primary air and forced draft fans can have their inlets close to the hoppers of a precipitator. Any fly ash not transported out of the boiler area by the fly ash transport system can be drawn into the primary air fan inlet. This can cause extreme wear to a fan that is equipped with high efficiency blading, since such blading is not designed for use in particulate laden air.

The second category is fly ash that escapes collection by the precipitator, or is picked up from the hoppers after precipitation, and passes from the precipitator into the induced-draft fan (see Figure 5-34). Erosion of induced-draft fans caused by particulate carryover from precipitators has been a problem. Incidents of induced-draft fans being destroyed because of excessive dust loading to the fans have occurred. This problem has been addressed by installing fans that can experience reasonable life considering the efficiency of the collection equipment ahead of the fans.

5.7 TRANSPORT TO IMPOUNDMENT

The practice in North America for hydraulic sluicing of ash is for a slurry having a weight percentage of ash of about 15 to 16 percent by weight or a water-to-ash ratio of 6:1.

Pipeline velocities range from 1.4 m/s (4.5 ft/sec) to 3.6 m/s (12 ft/sec) with the lower part of the range for fly ash and the upper end for bottom ash.

In general, bottom ash slurry velocities rarely exceed 2.7 m/s (9 ft/sec).

It must also be kept in mind that these figures are for segregated sluicing of ash and that if bottom and fly ash are mixed for a common system, then other criteria must be observed. It has been reported that ash volumes on the order of 50 percent by volume of the ash/water slurry have been successfully sluiced in Poland and Russia. However, the number of installations and the type of piping material used as well as the type of pump utilized is unknown.

Recently, two U.S. utilities in the arid Southwestern part of the country have installed ash transport systems using a 1:1 ratio of water to ash in an effort to conserve water. Unlike most other ash transport pumping systems, these use positive displacement reciprocating pumps. These pumps find extensive application in oil field recovery and in slurry pipelines.

The mixture of ash and water has a consistency somewhat like toothpaste. With the lower velocities required, since fallout is not a problem, the impact wear on elbows and other fittings are not as severe. Plain carbon steel or select plastic materials are used for pipes to transport the ash for disposal. Long radius elbows with provision for wear resistance complete the system. It is not known if surfactants, to enhance the transport, are used.

Another U.S. utility has retrofitted a fly ash transport system to reduce the amount of water content of the ash pond. The systems utilizes a 1:1 ratio of ash to water. This is being done primarily for environmental reasons. The success of these installations, all retrofits, demonstrates the feasibility of reducing the amount of water required for ash transport.

Approximately 50 percent of the plants in North America sluice the ash hydraulically to impoundment. The other 50 percent convey the ash by pneumatic means or by truck to the final landfill. This practice is changing because of environmental regulations. In plants constructed since 1980, the ash is impounded dry.

It is curious that of the plants that sluice the ash hydraulically to disposal, only about 10 percent recycle the water. Pipe scaling and pump wear are the main objections to recycling the water.

Several industrial plants and at least one utility have attempted to reduce the amount of water used to transport ash to ultimate disposal. In this effort, the plants and utility installed transport systems, utilizing viscous shear pumps for conveying the ash.

Viscous shear pumps operate in a manner analogous to viscous shear variable speed couplings. The fluid to be pumped is introduced between two parallel discs that are flat. The fluid is accelerated from the center portion of the disc to the outer periphery, by centripetal force, where it is discharged into a pipe.

The theory is that a boundary layer that does not move ("no-slip condition") exists at the face of the disc, and that the fluid adjacent to it does move by viscous shear without contacting the surface. By doing so, the discs experience little or no wear.

The advantages claimed for this design are the capability to pump higher solids content fluids with reduced wear and subsequently lower maintenance costs.

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The disadvantages are high initial cost and low efficiencies compared to other types of materials handling pumps. Typically, these efficiencies are less than 50 percent.

These pumps can be configured with multiple disc sets and can achieve high capacities and discharge pressures.

So far, the results with pumping ash are mixed. One utility has discontinued the experiment. This is not to imply that without more testing, they cannot successfully be used in this service, since they have been successful in pumping other slurry materials.

Over the years, many types of piping materials and wear resistant fittings have been used in an attempt to reduce the wear from abrasions and prolong the life of the systems. Heavy wall steel pipe, heat treated alloy steels, case hardened steel, solid basalt, basalt lined, and various plastic piping materials have been used in transport systems with varying degrees of success. The ash composition, size, the transport water quality and the velocity within the system are all contributing conditions in selecting a suitable material.

Fittings, most notably elbows, have also had various materials and configurations investigated. Extra long sweep, wear backs that are replaceable and recessed entry areas have all been utilized. See Figure 5-35.

Recent experience in the United States with a ceramic-lined fiberglass reinforced epoxy pipe has demonstrated that it is well suited for ash handling applications. Used with suitable elbows, it has proven to be a good solution for most ash services. First introduced in the mid-1970s, this particular material has given good service in bottom and fly ash transportation, with a typical expected life being 17 years.

Another material, urethane-lined steel pipe, has given excellent service in handling abrasive bottom ash. It should be noted that this material is expensive.

5.8 OBSERVATIONS AND SUGGESTIONS

For a high ash lignite, the use of a submerged scraper chain for continuous bottom ash removal is a good choice. The dry chain system should be investigated for all of the obvious advantages it offers.

When burning coal with such a high ash content, it is good practice to continuously remove ash from the economizer, air preheater, and in applicable cases, the precipitator.

Although plants utilizing air slides were not observed, it is assumed the air slides operated intermittently (i.e., not continuously conveying). If compressed air consumption is not excessive, these slides can be fitted with rotary air locks at the hopper discharge and operated in a continuous mode.

Air slides present elevation difficulties since the slide must decline to the top of the intermediary hoppers, limiting their height and, to that extent, capacity. It also requires dual handling systems and several additional dust collection devices.

If the ash is to be transported hydraulically, there are environmental as well as economic conditions to consider, including runoff water collection, impounding, recycling of the transport water, and dust, although, the dust problem is common to any of the means of disposal. Other considerations are those of the pumps, piping, pipe fittings, and the availability and quality of the sluicing water.

Increasing the size of the existing ash disposal pile will entail extending the area of the ash pile, or increasing the height of the pile, or both, which will require increased head from the pumps. With dry transport of fly ash, the required flow capacity for the existing pumps will decrease. This decrease may allow the pumps to be used without modification for an extended ash pile for some time.

With continued hydraulic transport of the ash, the piping as it wears out from erosion, can possibly be replaced with pipe of a different material having improved wear ability and a longer service life than steel pipe.

Two such pipe materials that were reviewed are basalt-lined steel pipe and ceramic core fiberglass reinforced epoxy pipe. Both have been used extensively for ash transport in power plants, and both give significantly longer service life compared to steel.

On-site disposal utilizing trucks rather than other means of conveyance should certainly be studied.

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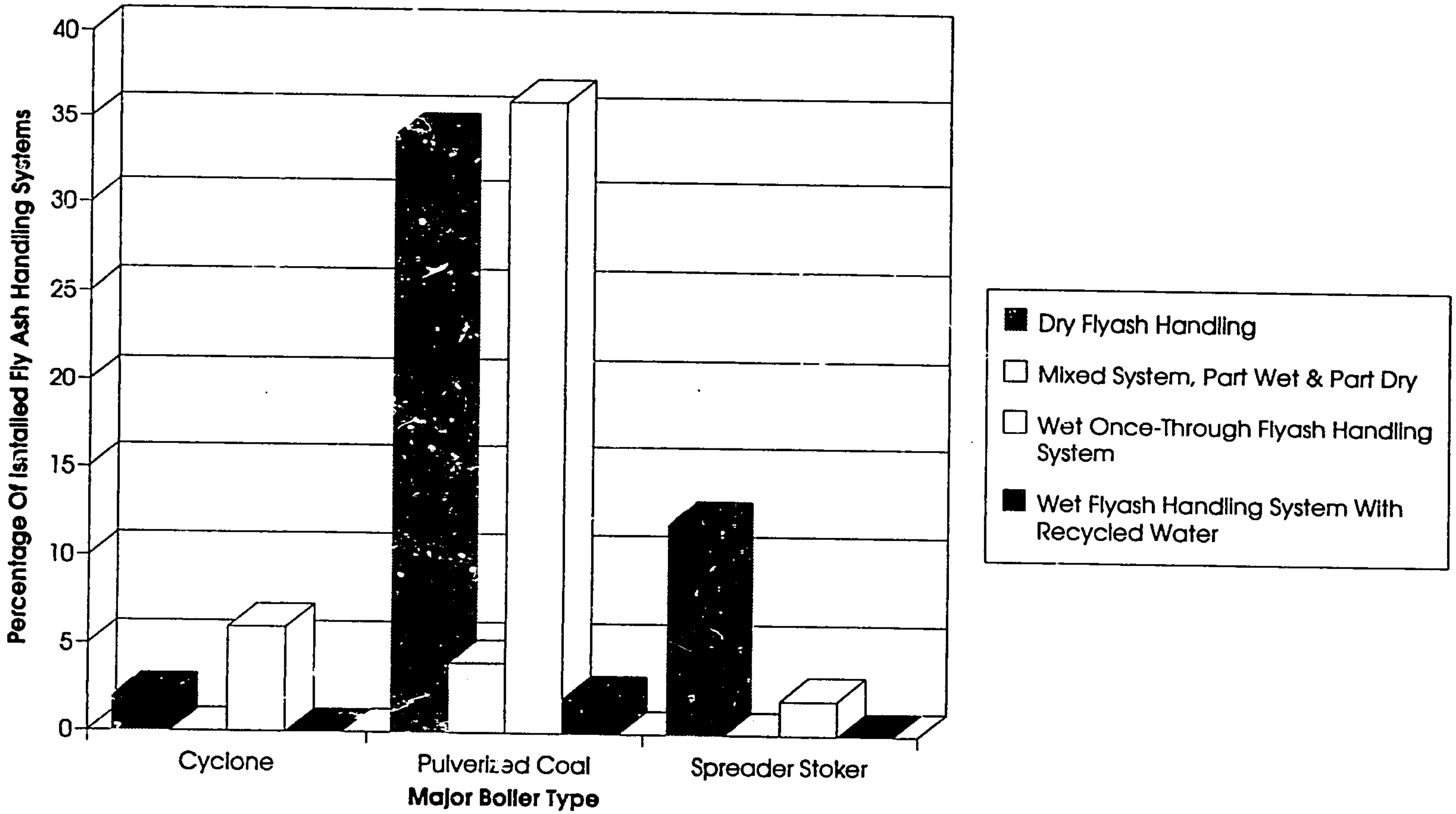


Figure 5-1 North American Fly Ash Handling Systems by Boiler Type

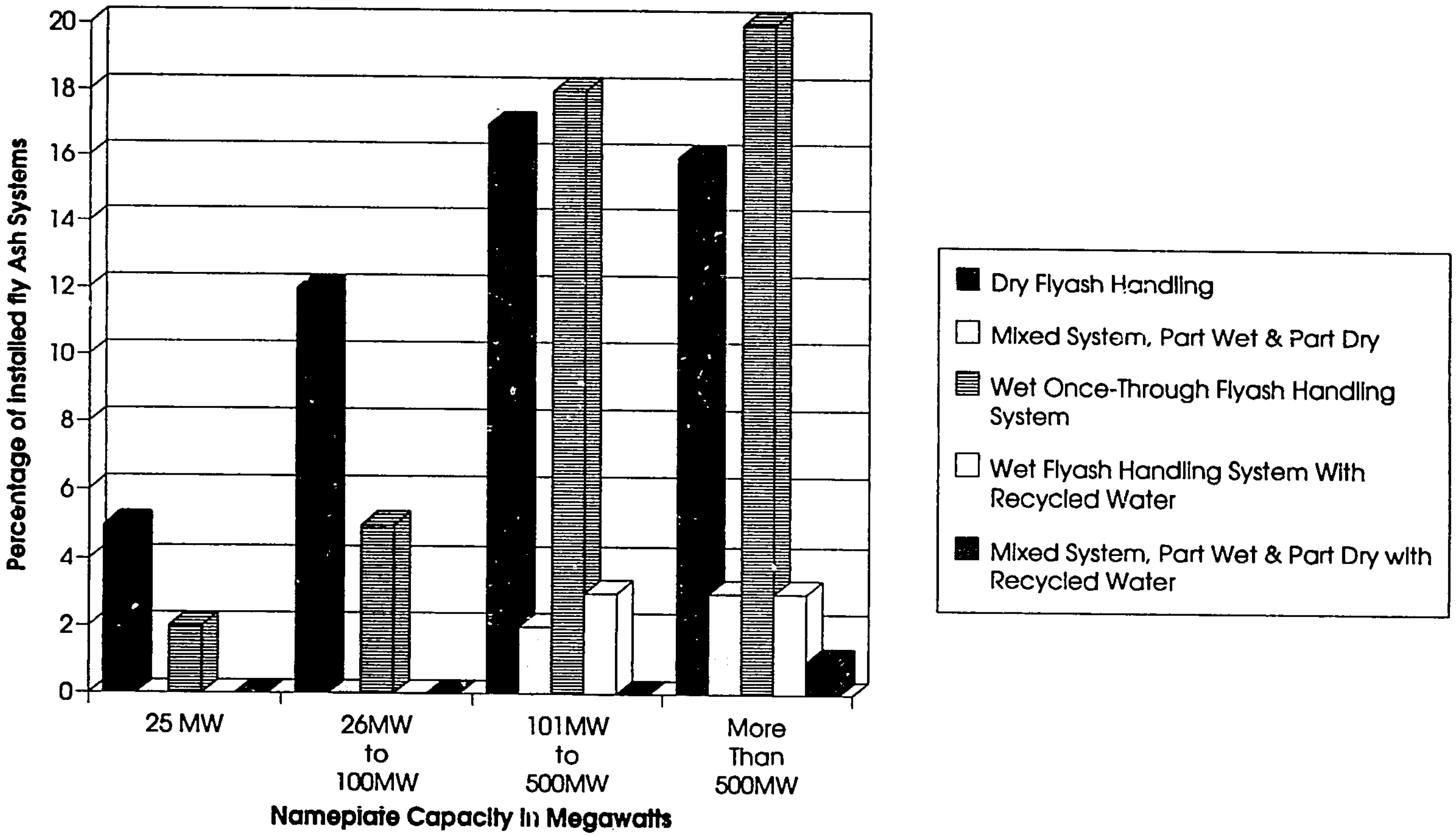


Figure 5-2 North American Fly Ash Handling Systems by Boiler Size

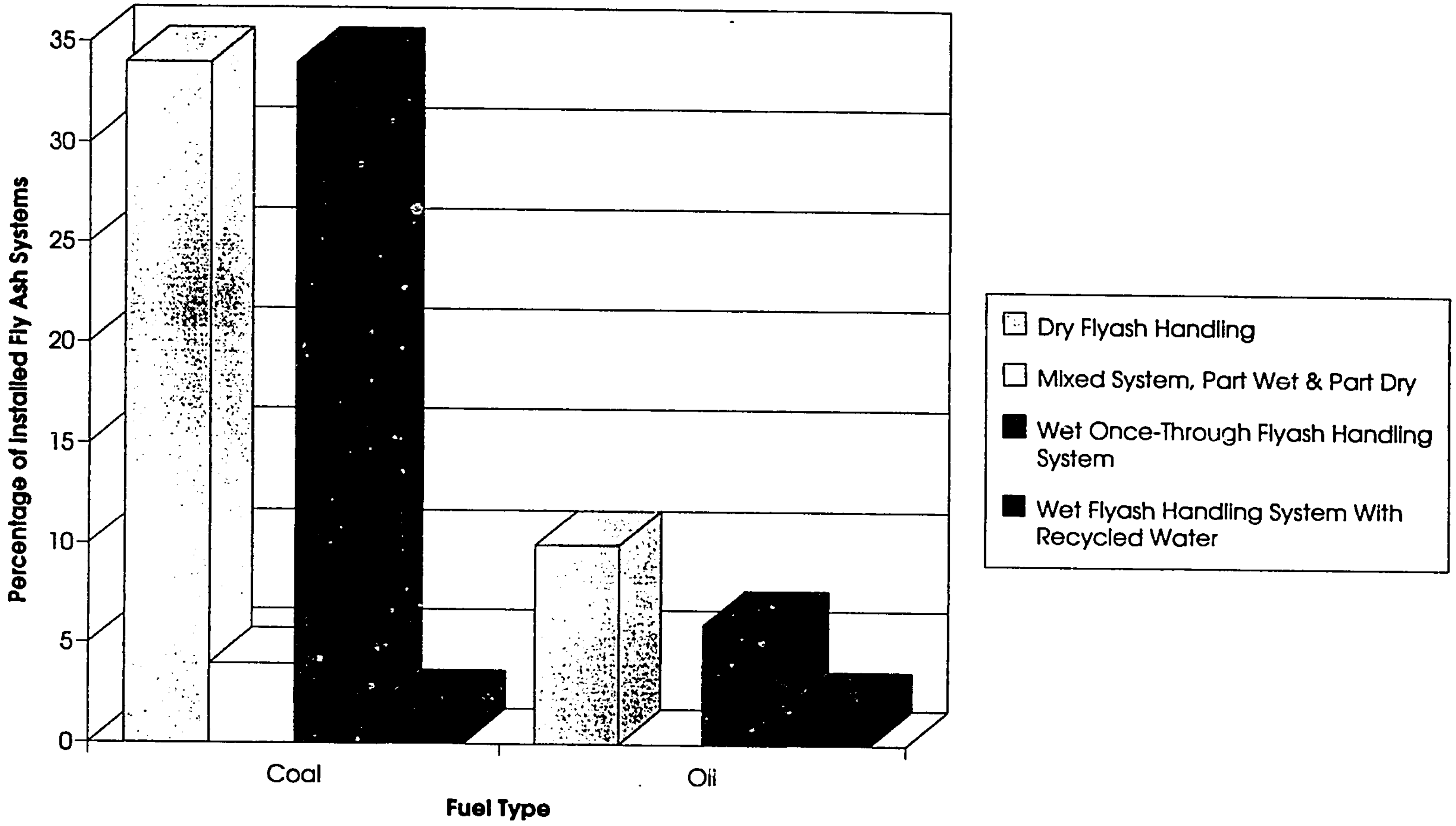


Figure 5-3 North American Fly Ash Handling Systems by Fuel Type

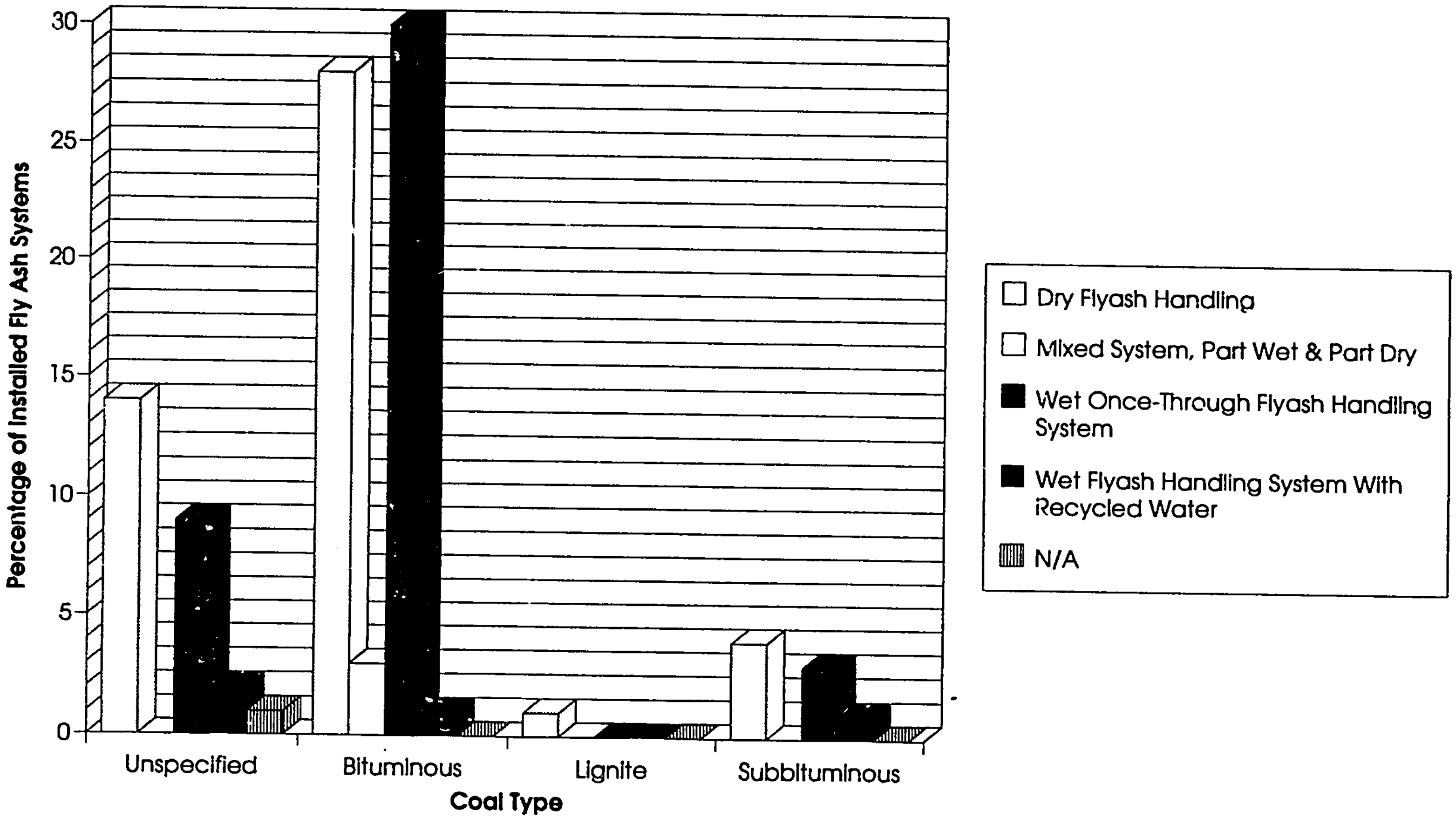
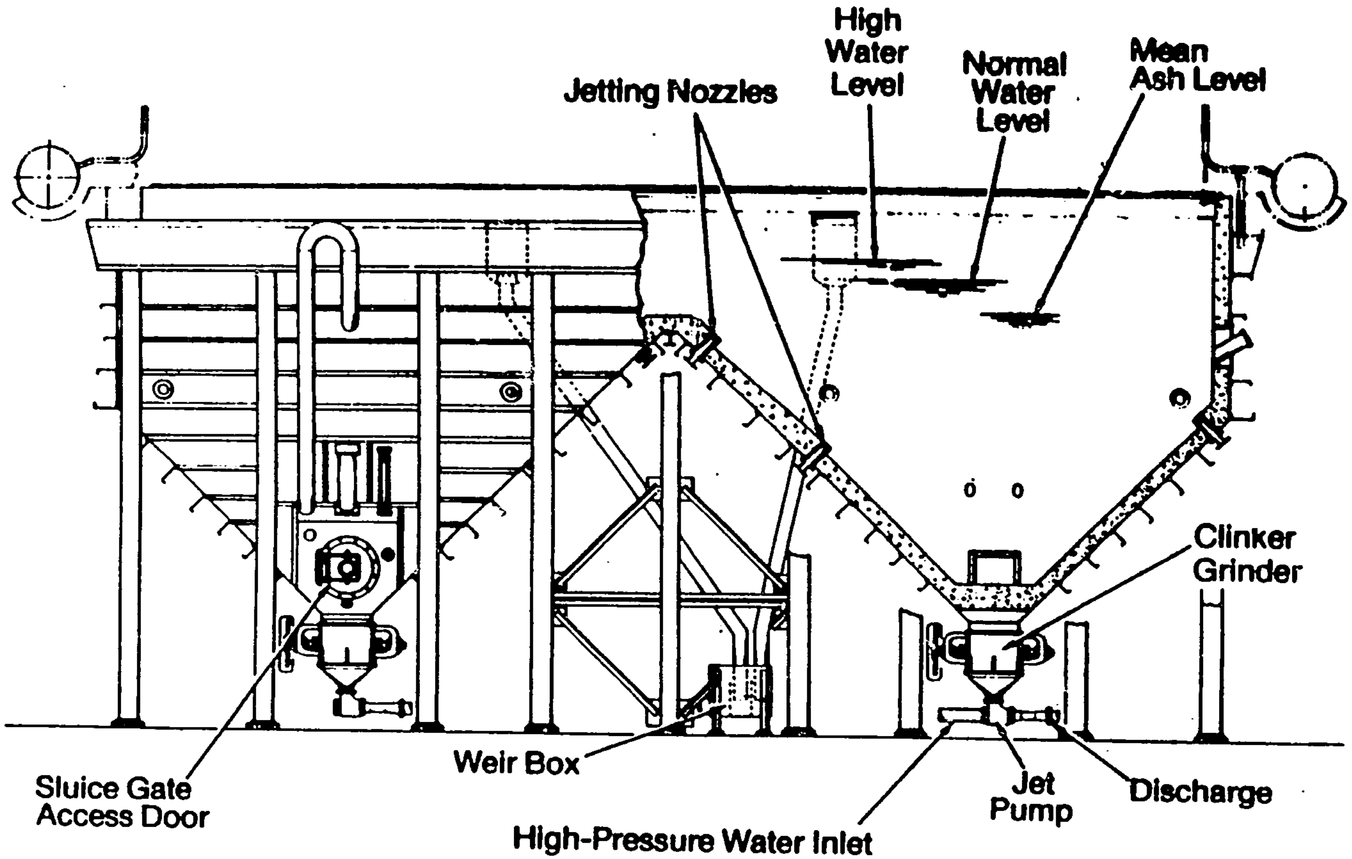


Figure 5-4 North American Fly Ash Handling Systems by Type of Coal



Combustion Fossil Power Systems, Combustion Eng., Inc.

Figure 5-5 Water Impounded Bottom Ash Hopper

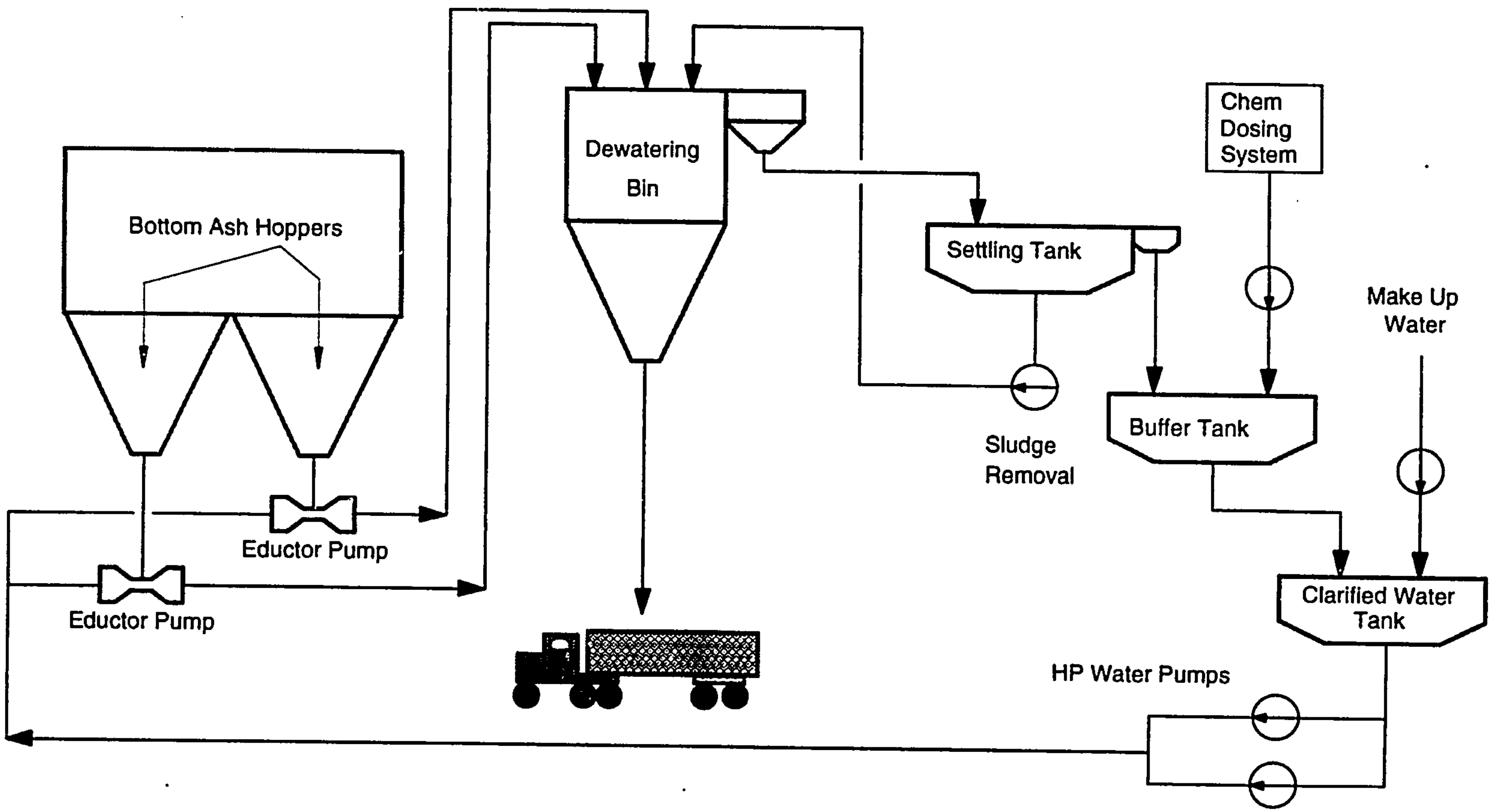


Figure 5-6 Typical Bottom Ash Water Impounded Hopper Collection System

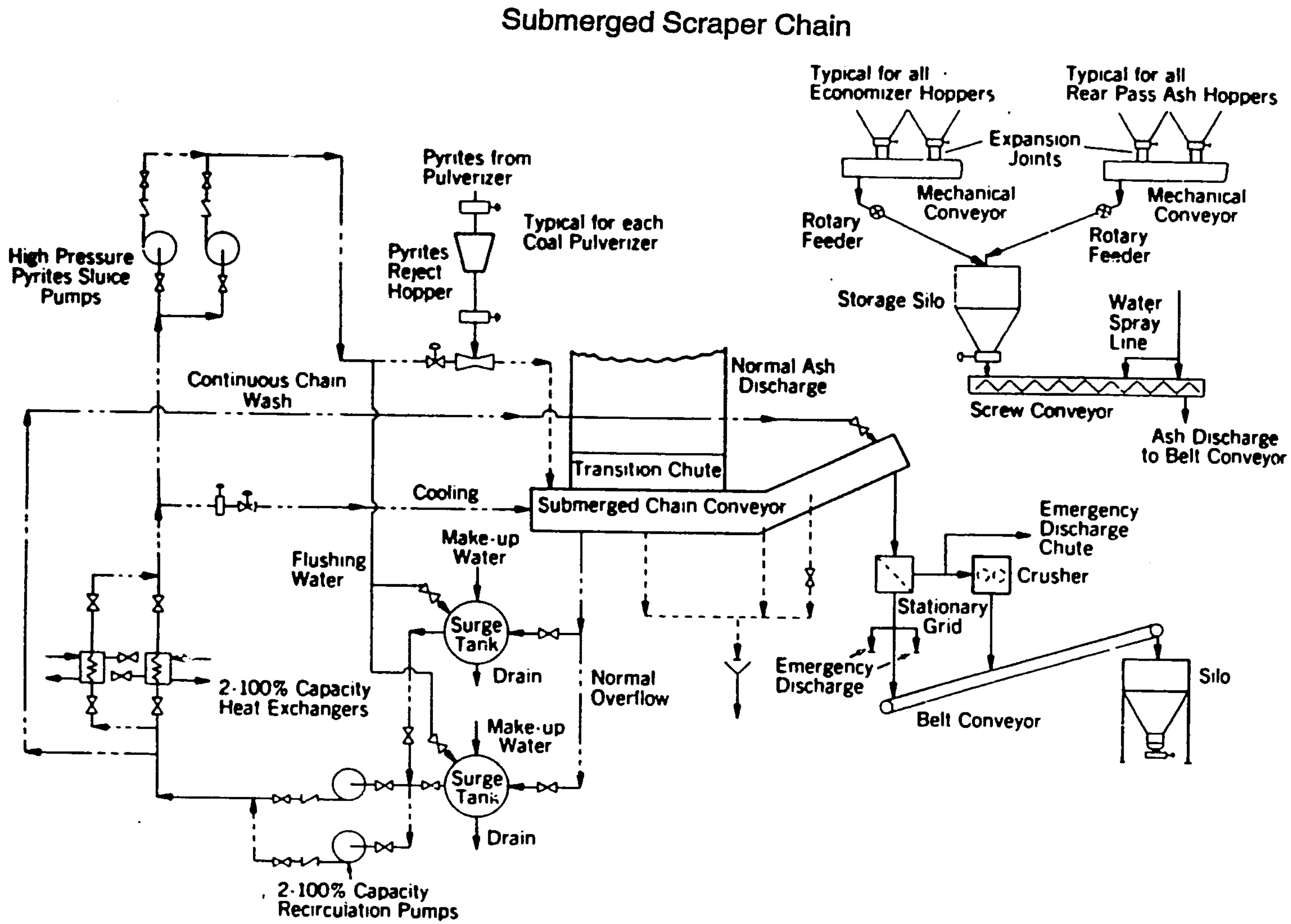


Figure 5-7 Typical Bottom Ash and Economizer Ash System

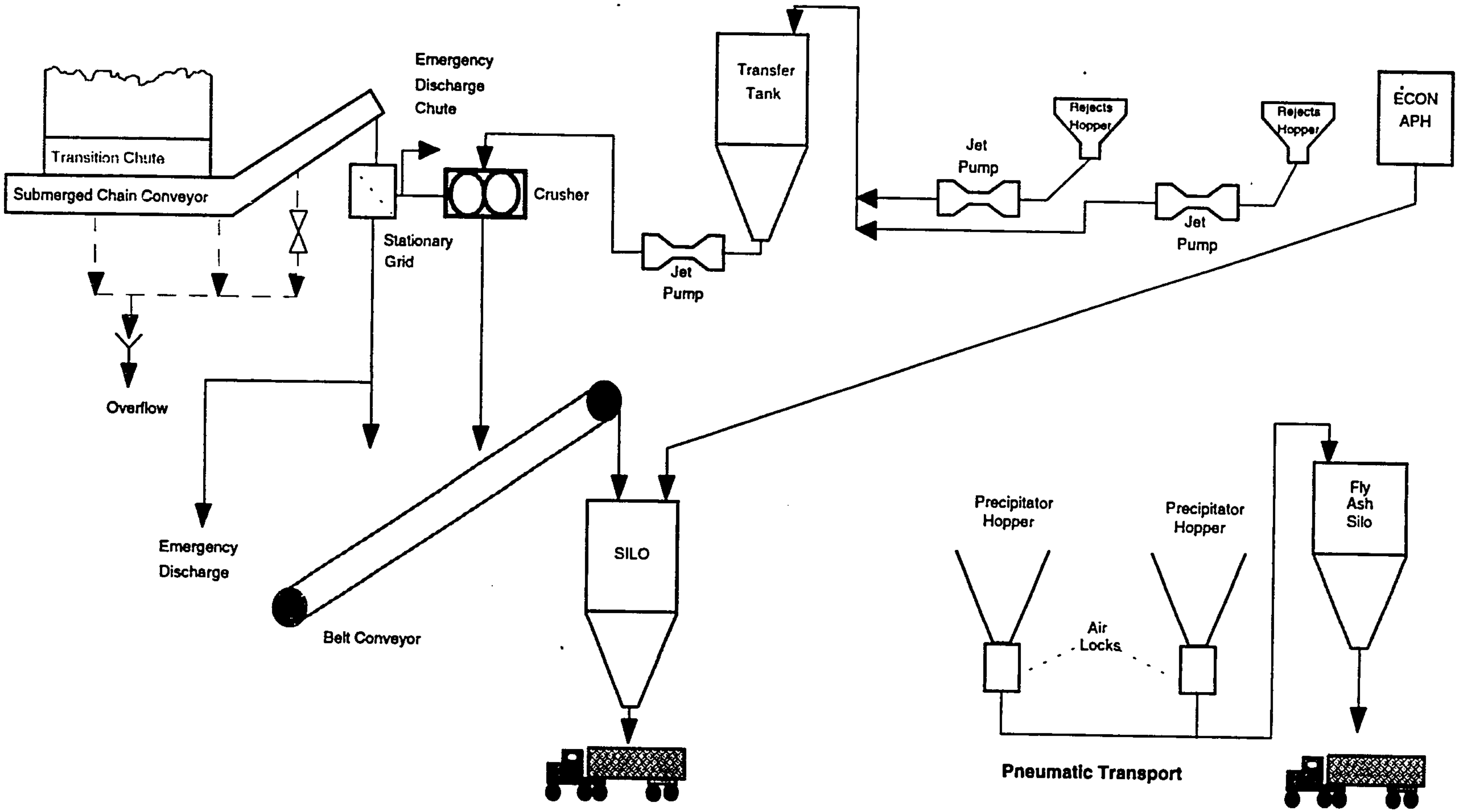


Figure 5-8 Wet and Dry Collection System

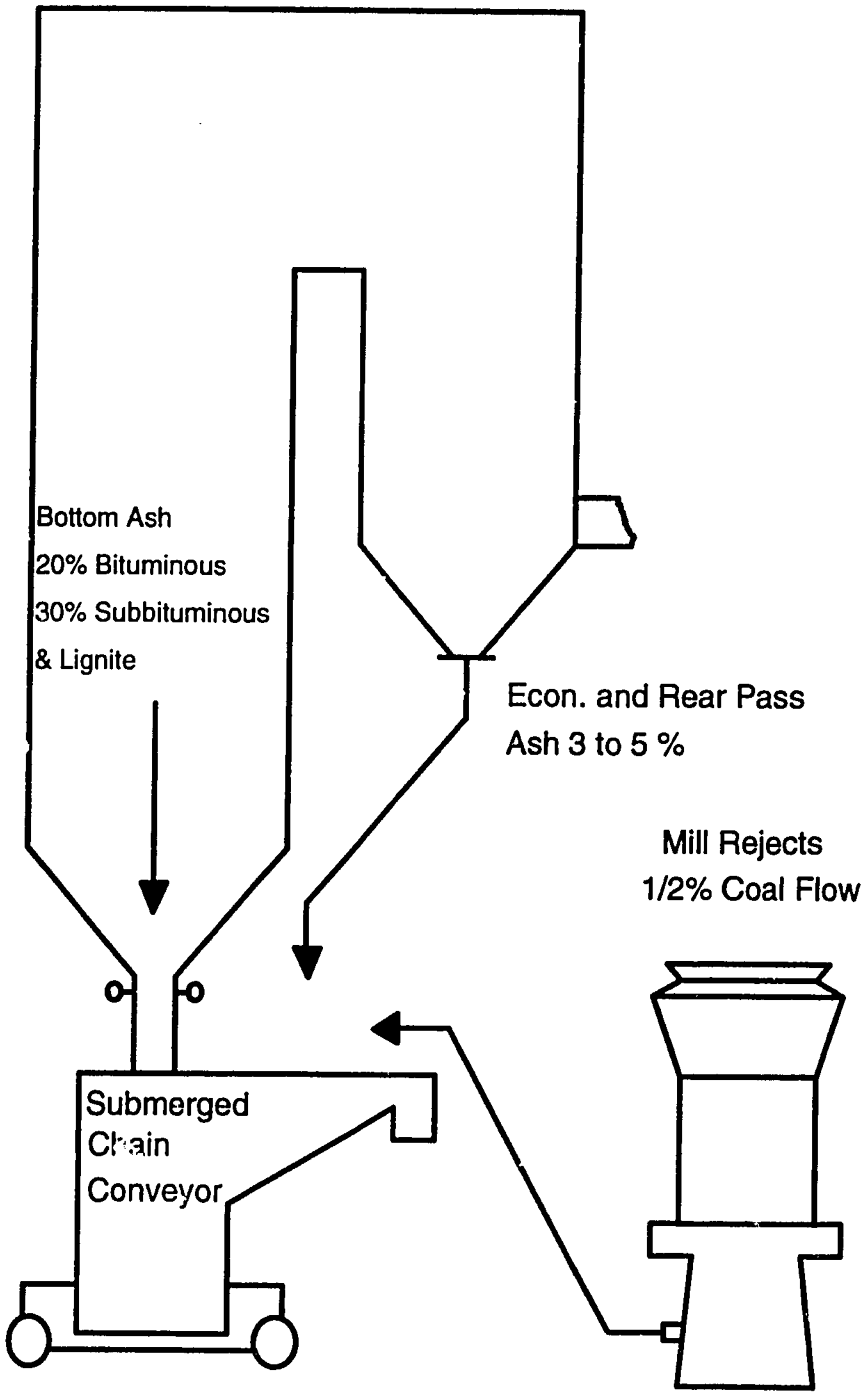


Figure 5-9 Typical Ash Distribution

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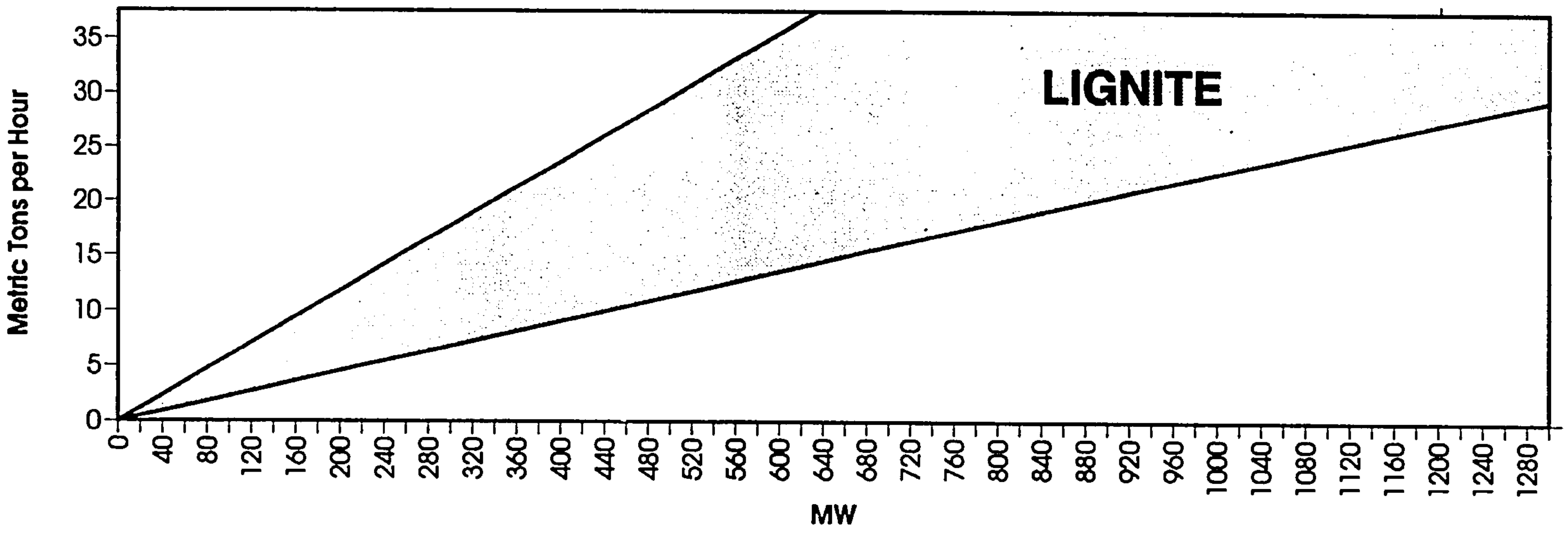


Figure 5-10a Ash Rates Based on Type of Coal – Lignite

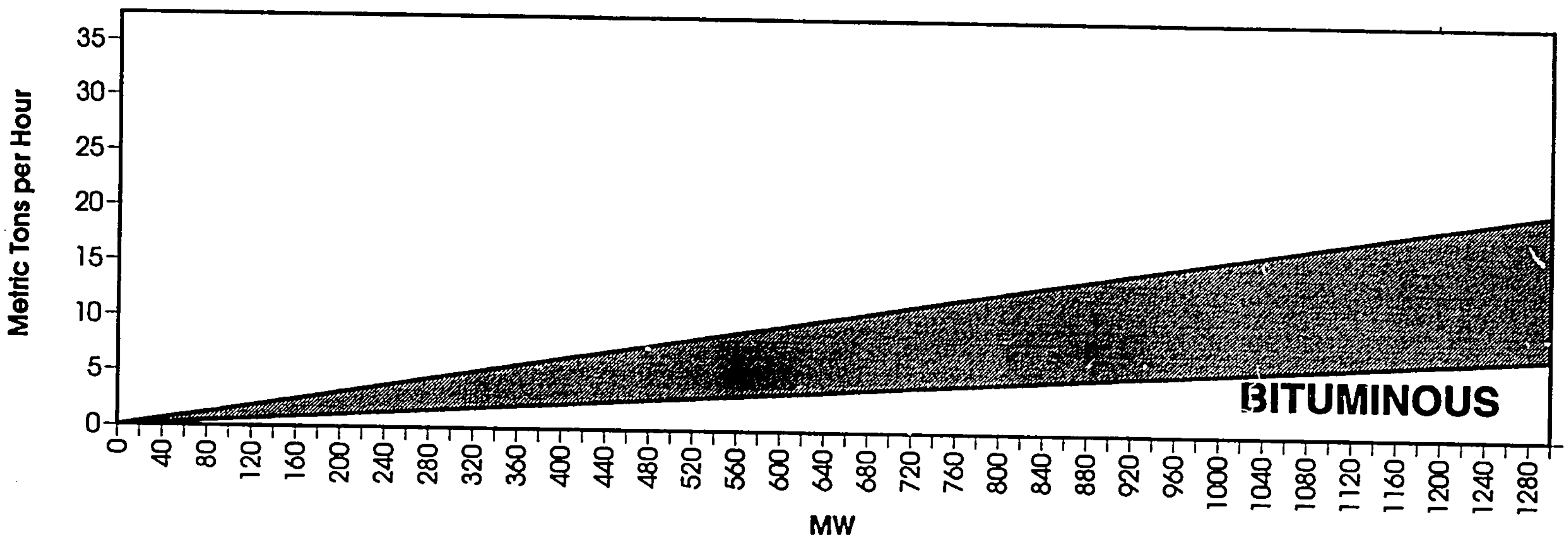


Figure 5-10b Ash Rates Based on Type of Coal – Bituminous

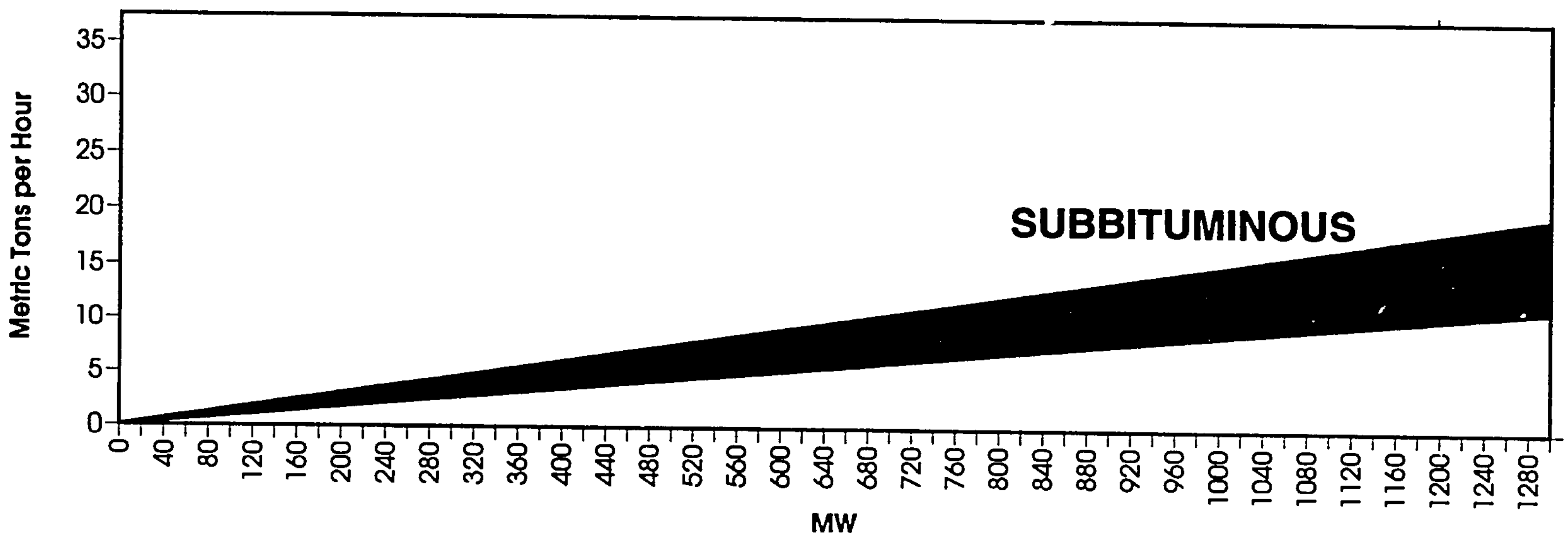


Figure 5-10c Ash Rates Based on Type of Coal – Subbituminous

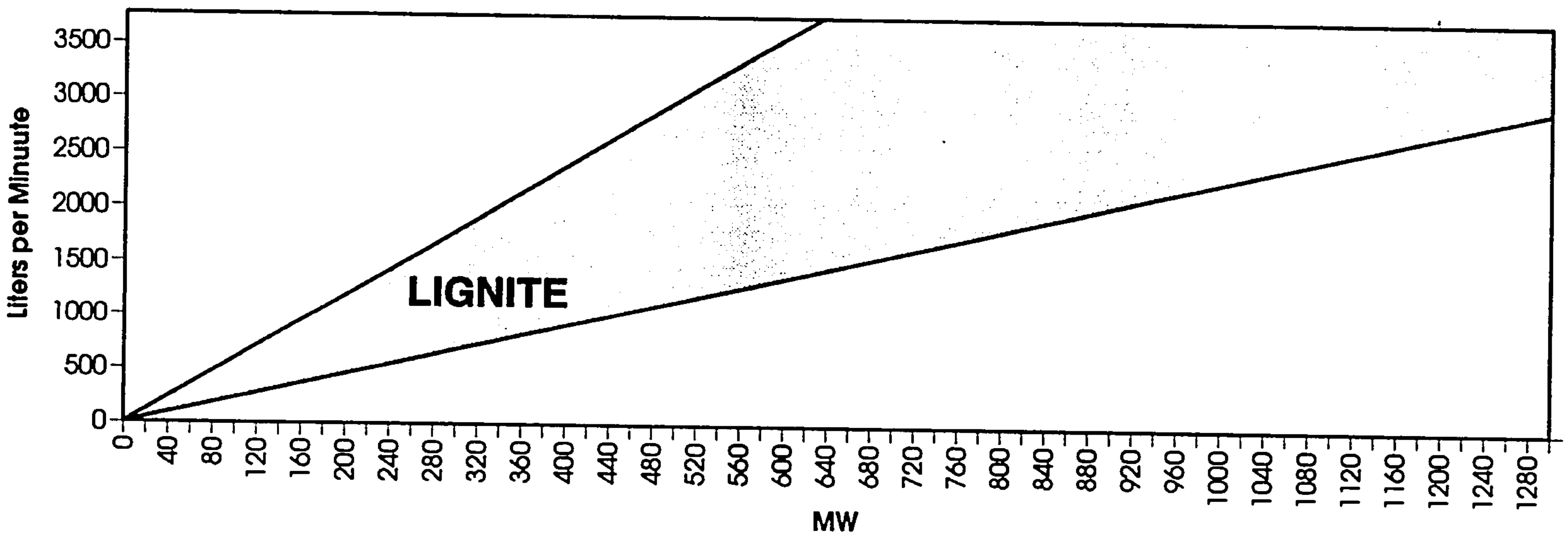


Figure 5-11a SCC Closed-Loop Cooling Requirements – Lignite

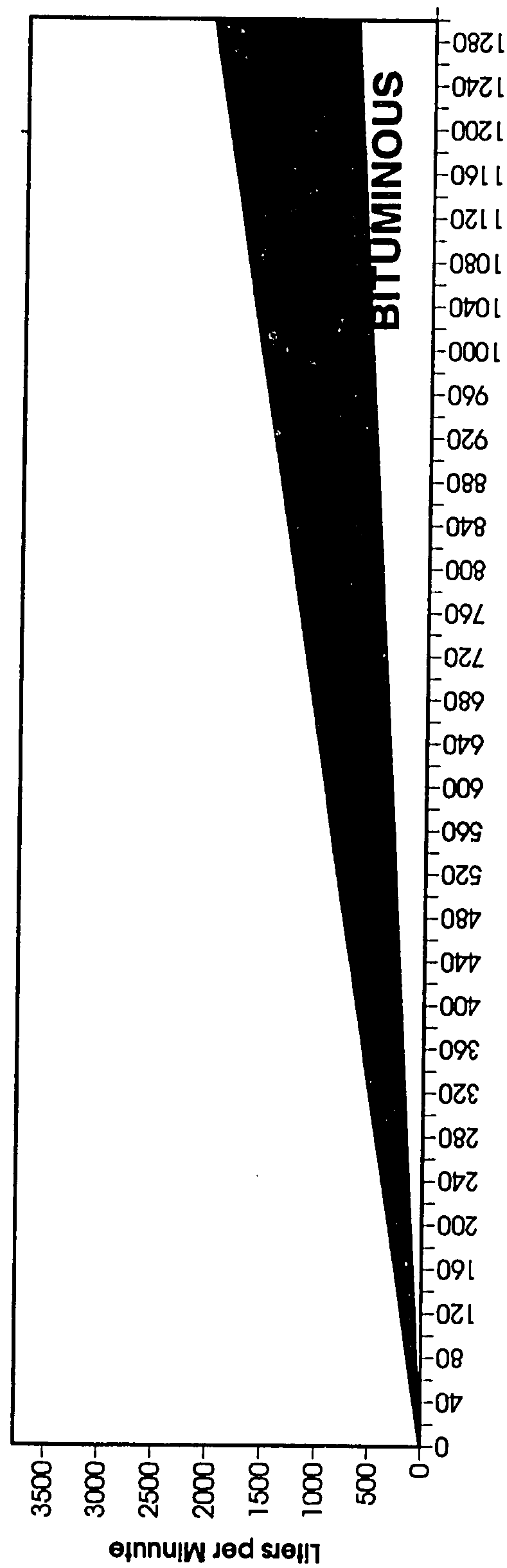


Figure 5-11b SCC Closed-Loop Cooling Requirements – Bituminous

9b

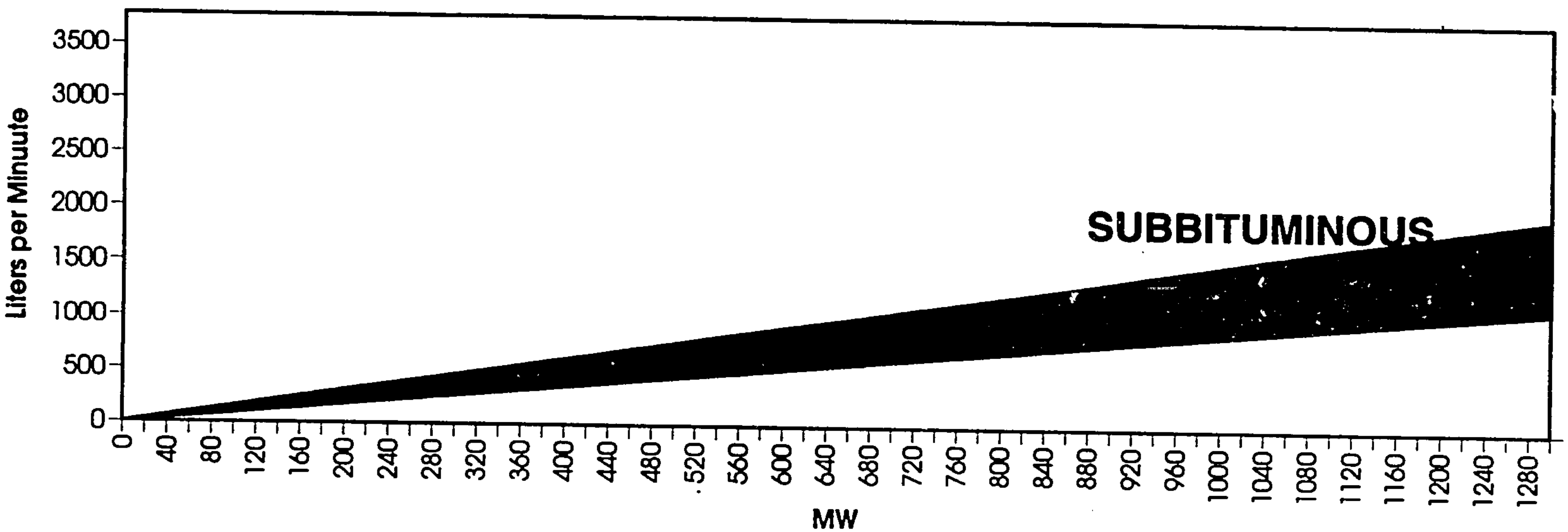


Figure 5-11c SCC Closed-Loop Cooling Requirements – Subbituminous

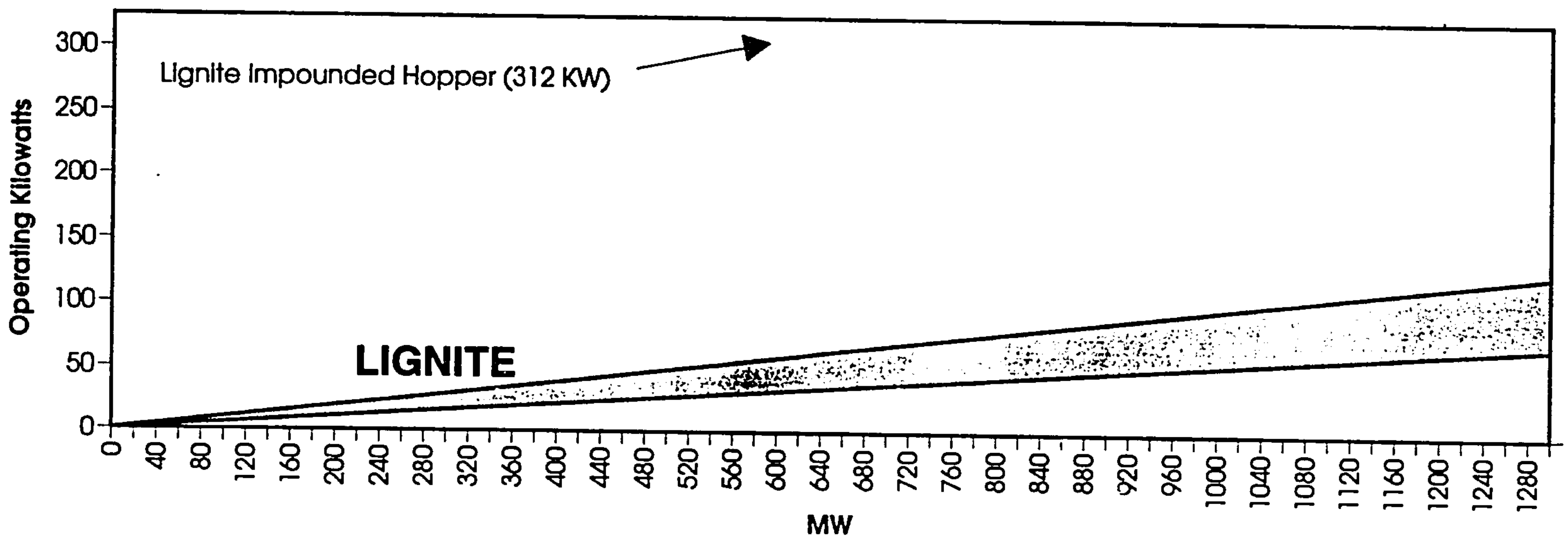


Figure 5-12a SCC Operating KW – Lignite

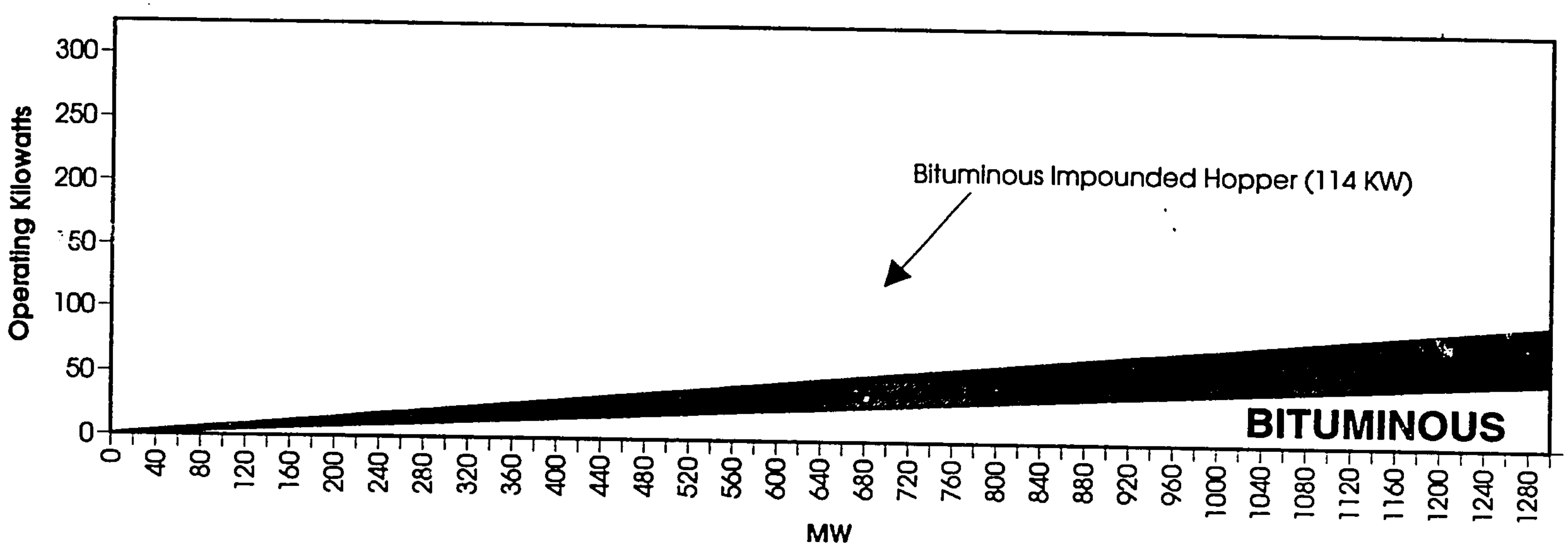


Figure 5-12b SCC Operating KW – Bituminous

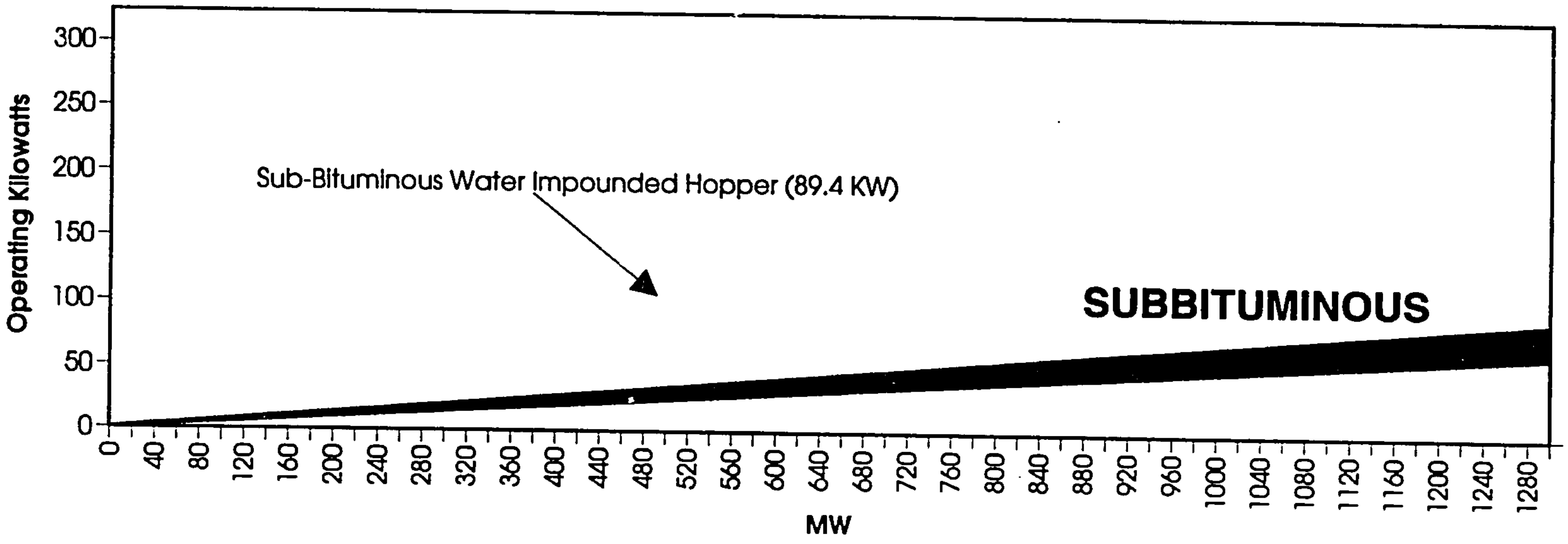
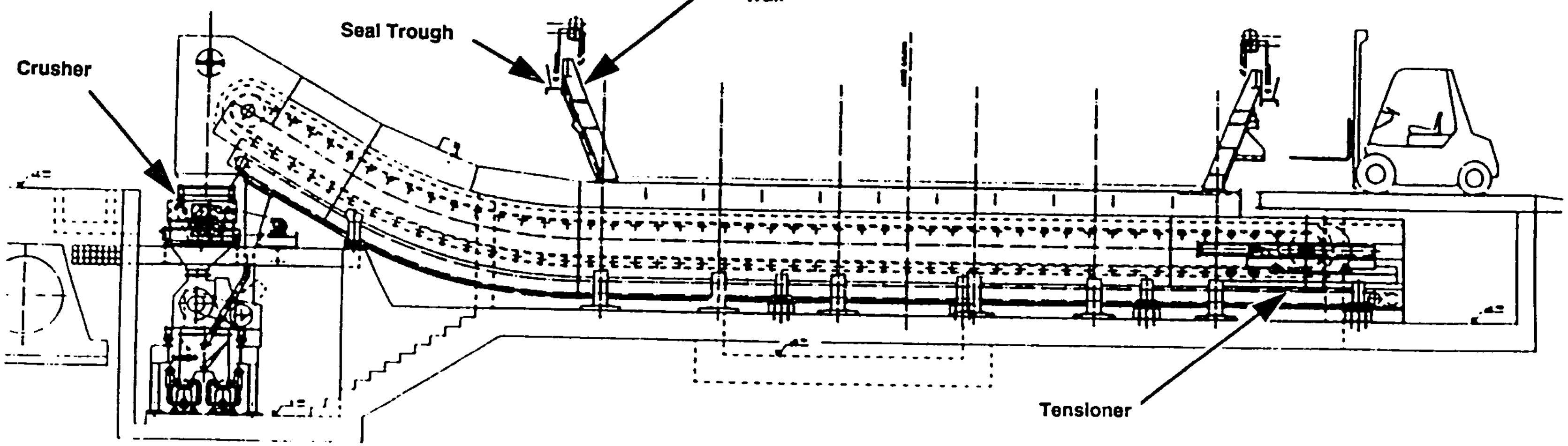


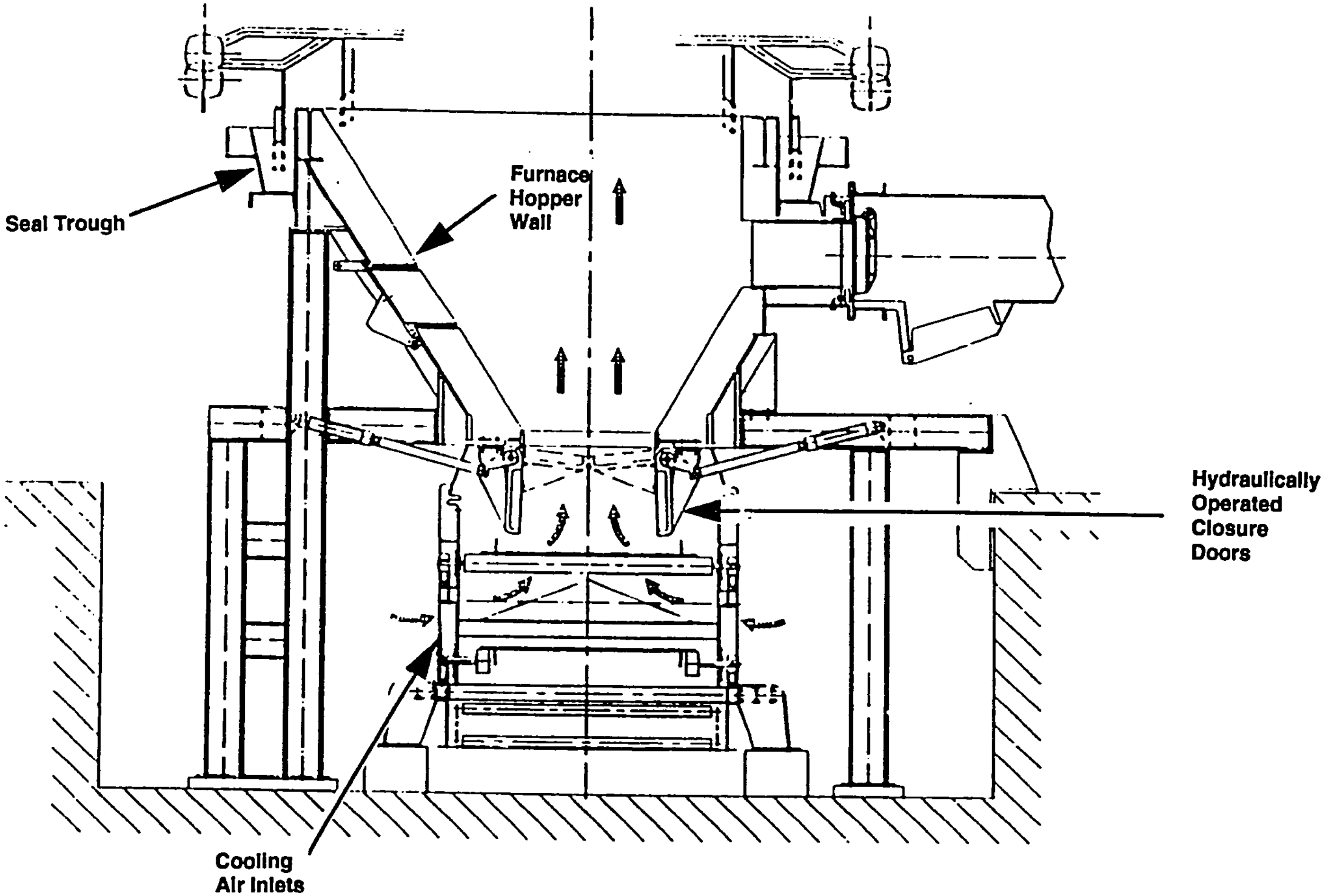
Figure 5-12c SCC Operating KW – Subbituminous

Bottom Ash



United Conveyor Corp.

Figure 5-13 Dry Scraper Chain



United Conveyor Corp.

Figure 5-14 Dry Scraper Chain Furnace Bottom Hopper

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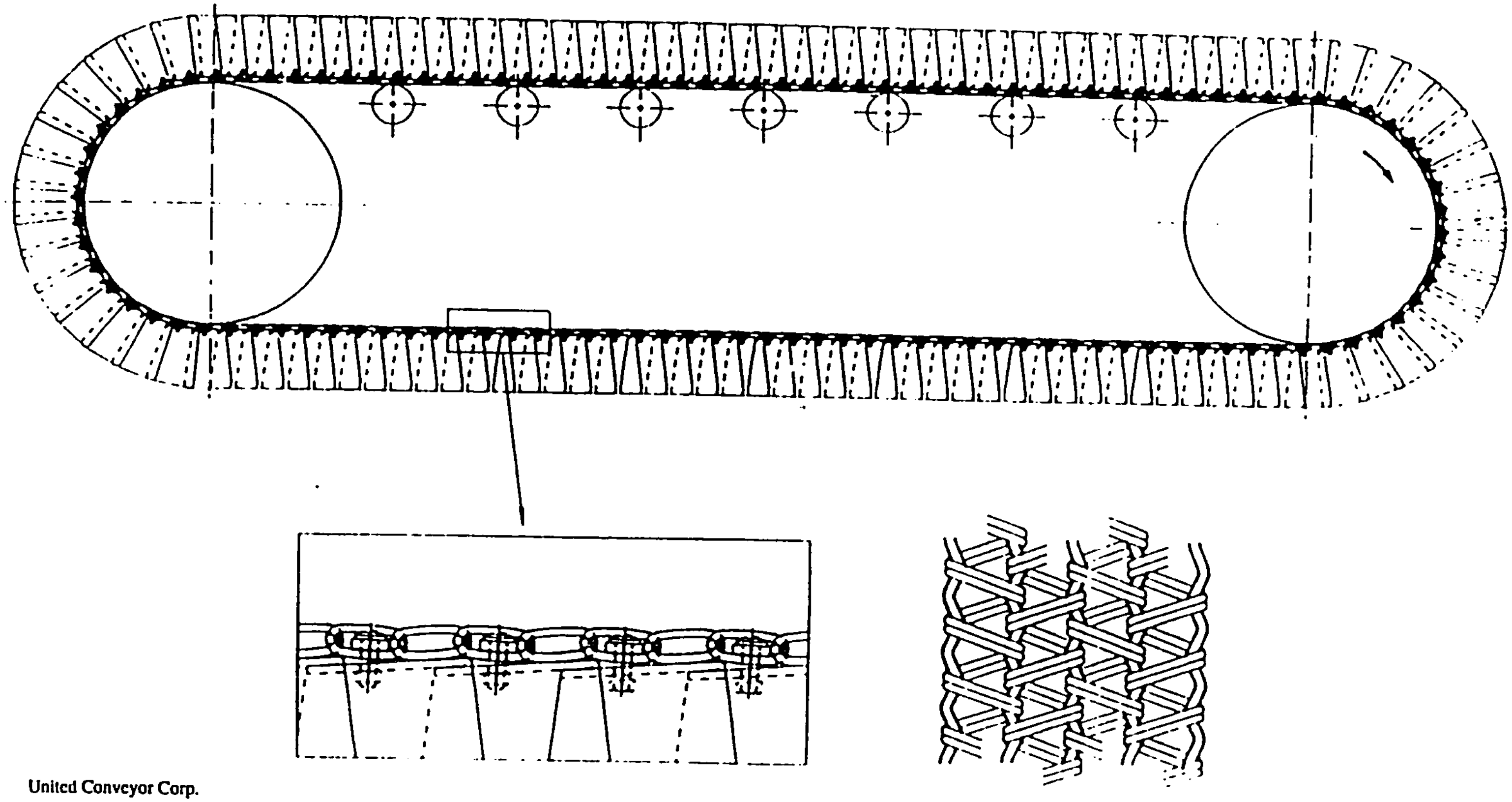
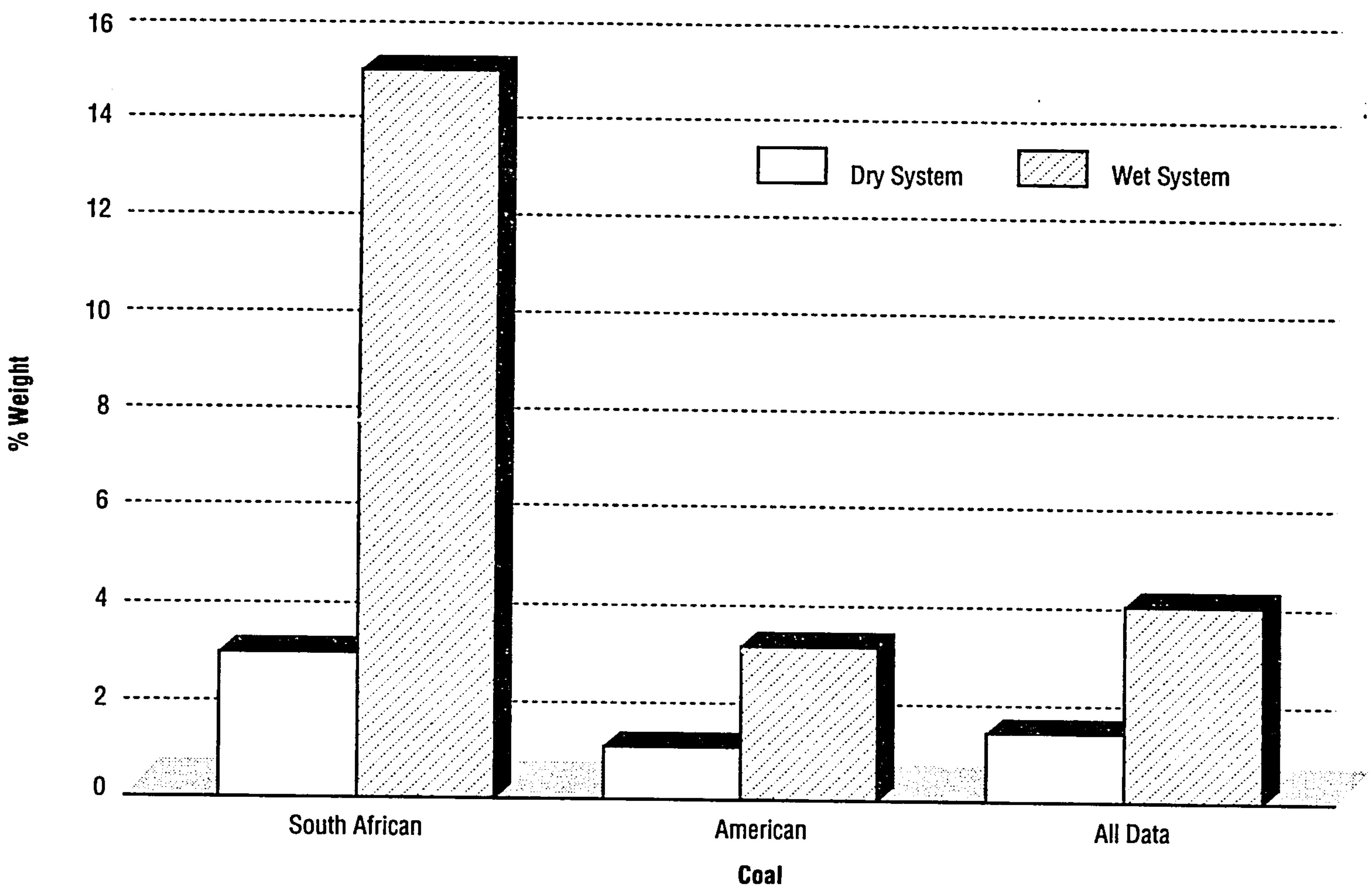
Stainless Steel Belt



United Conveyor Corp.

Figure 5-15 Dry Bottom Ash Extraction System

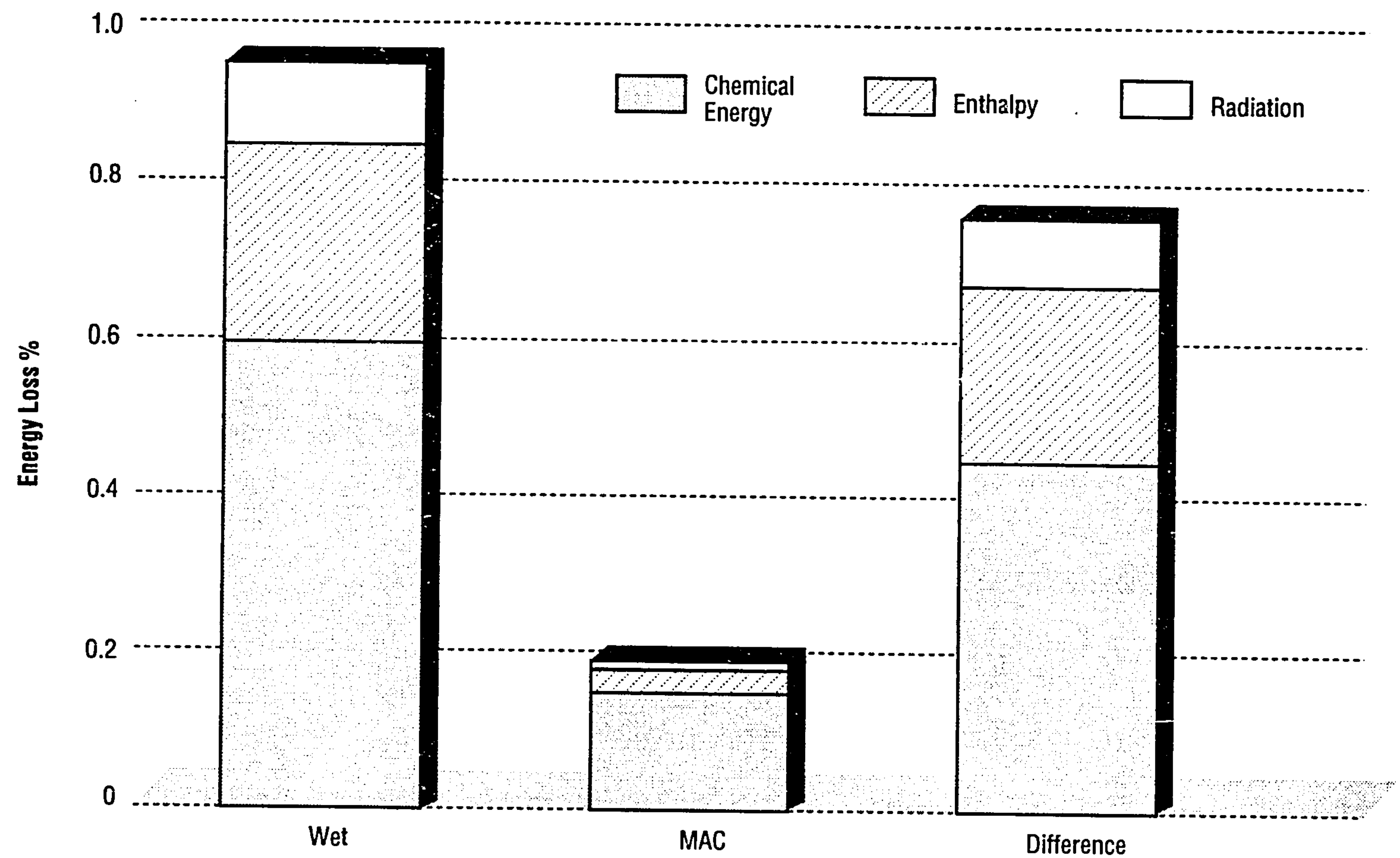


Data from United Conveyor Corp.

94-1685b.003

Figure 5-16 Carbon Content in Bottom Ash

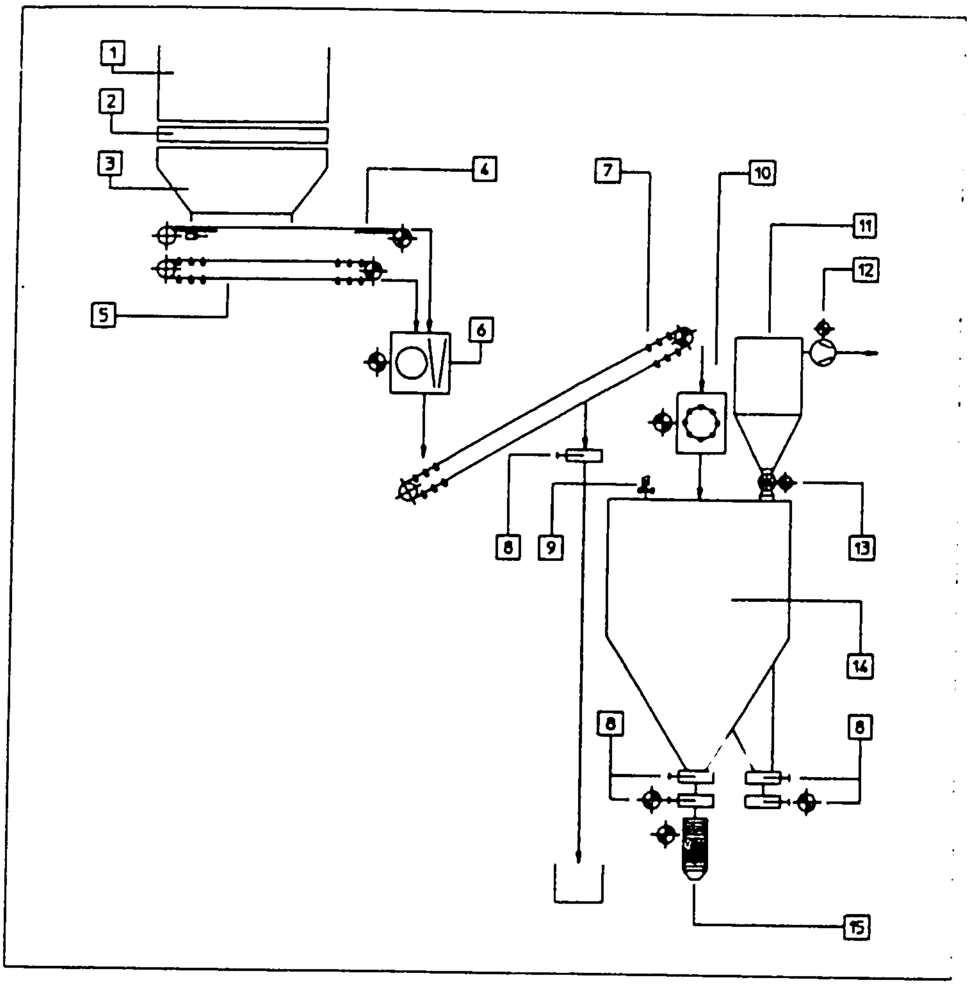
104



Data from United Conveyor Corp.

94-1685b.004

Figure 5-17 Energy Loss Wet System vs Dry System 200 Mwe Coal Feed: 35% ash

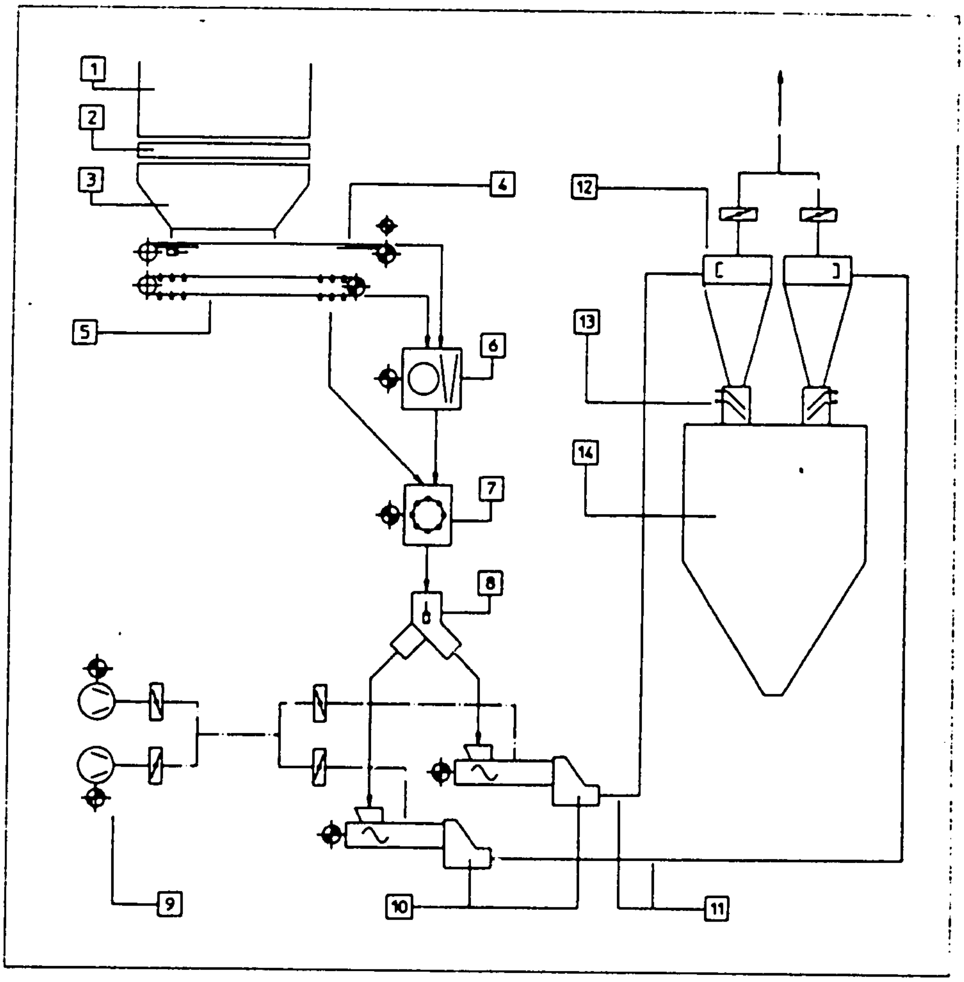


Magaldi ash conveyor with mechanical handling system

1 - Boiler
2 - Hydraulic seal
3 - Ash hopper
4 - MAC extractor
5 - Cleaning drag chain
6 - Primary crusher
7 - Drag chain conveyor
8 - Shutoff valve
9 - Saiety valve
10 - Crusher
11 - Filter
12 - Blower
13 - Rotary air lock
14 - Silo
15 - Telescopic loader

United Conveyor Corp.

Figure 5-18 Magaldi Ash Conveyor with Mechanical Handling System



Magaldi ash conveyor with pneumatic handling system

1 - Boiler	6 - Primary crusher	11 - Pneumatic conveying pipes
2 - Hydraulic seal	7 - Secondary crusher	12 - Cyclone separator
3 - Ash hopper	8 - Change-over valve	13 - Double flap valve
4 - MAC extractor	9 - Compressor	14 - Silo
5 - Cleaning drag chain	10 - Screw pump	

United Conveyor Corp.

Figure 5-19 Magaldi Ash Conveyor with Pneumatic Handling System

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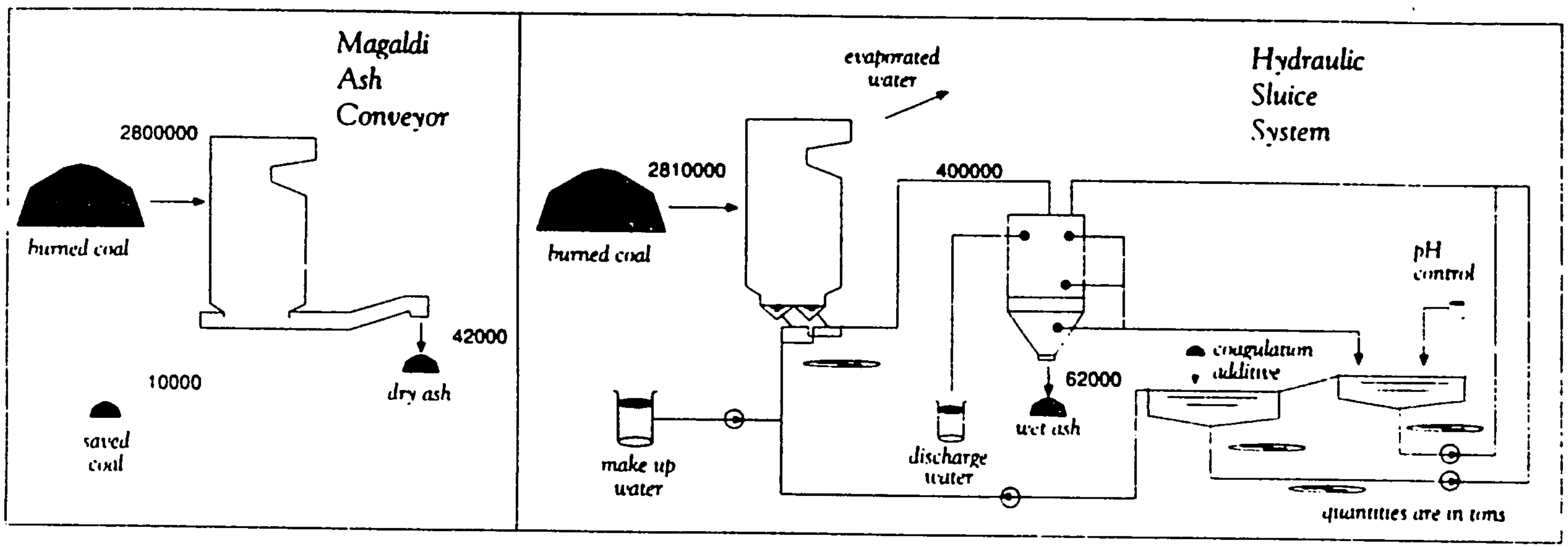
Quantities are in Tons



United Conveyor Corp.

Figure 5-20 4 x 300 MWe One-Year Material Balance

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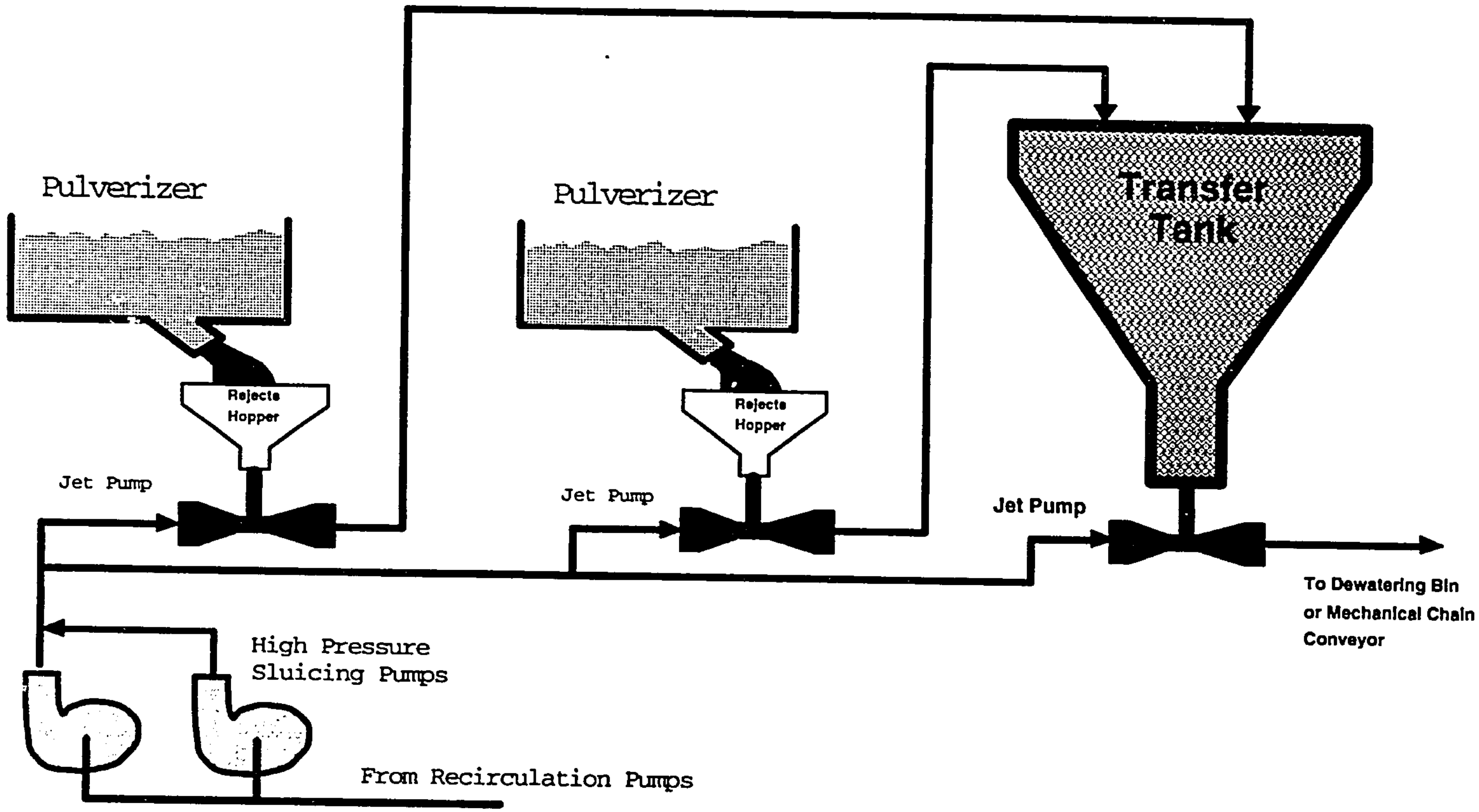
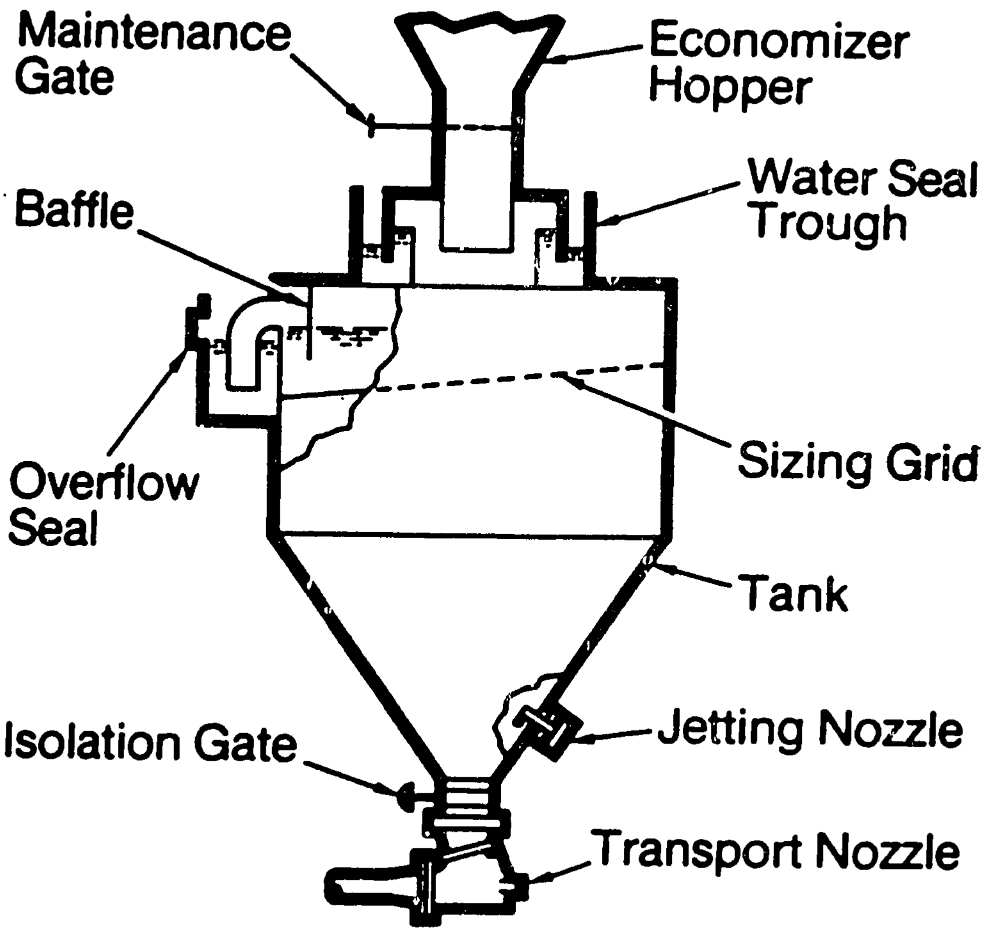


Figure 5-21 Pulverizer Rejects Handling



Water-filled tank beneath economizer hopper
for low-calcium-content ash

Combustion
Fossil Power Systems
Combustion eng., Inc.

Figure 5-22 Water-Filled Economizer Hopper Tank

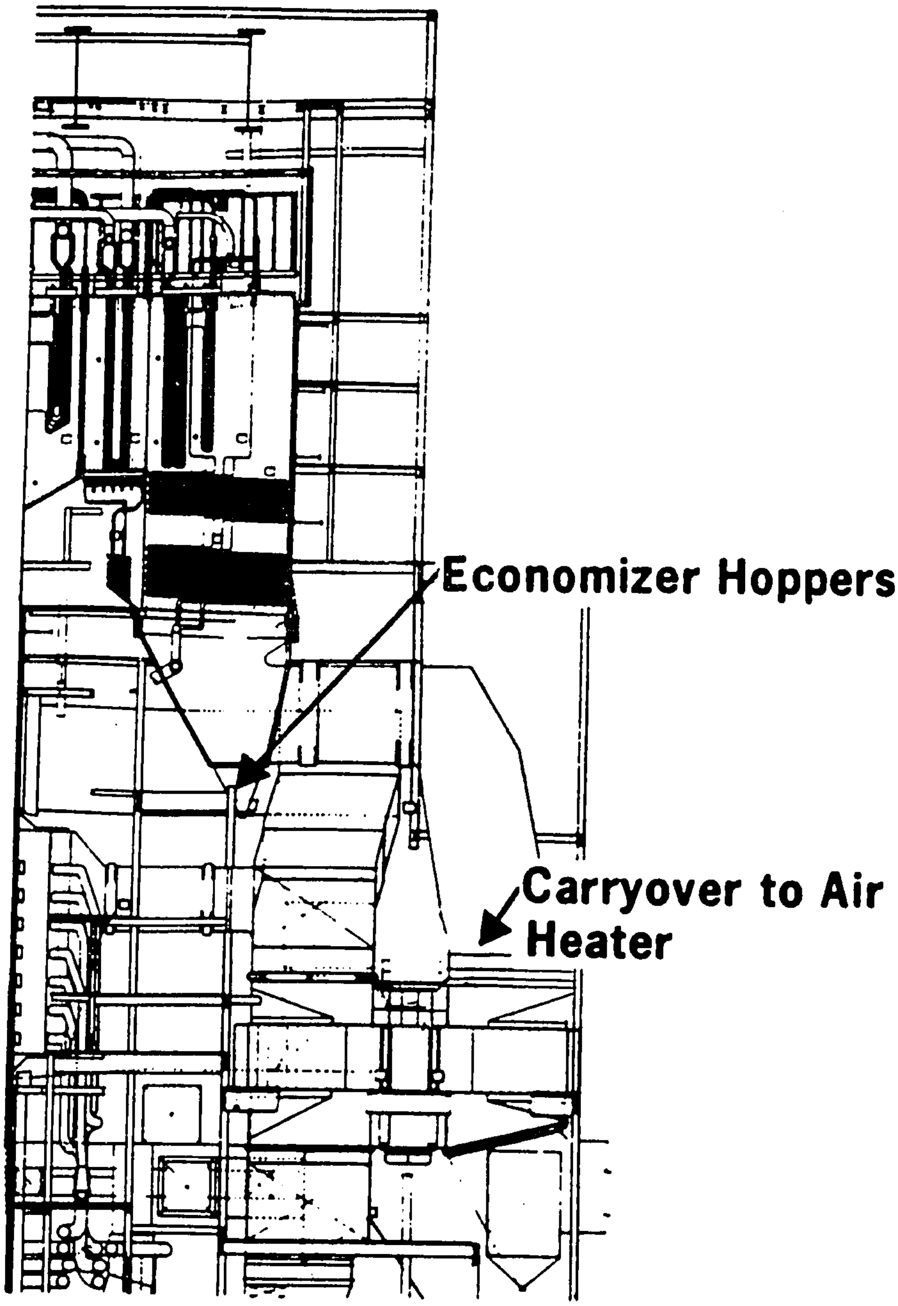
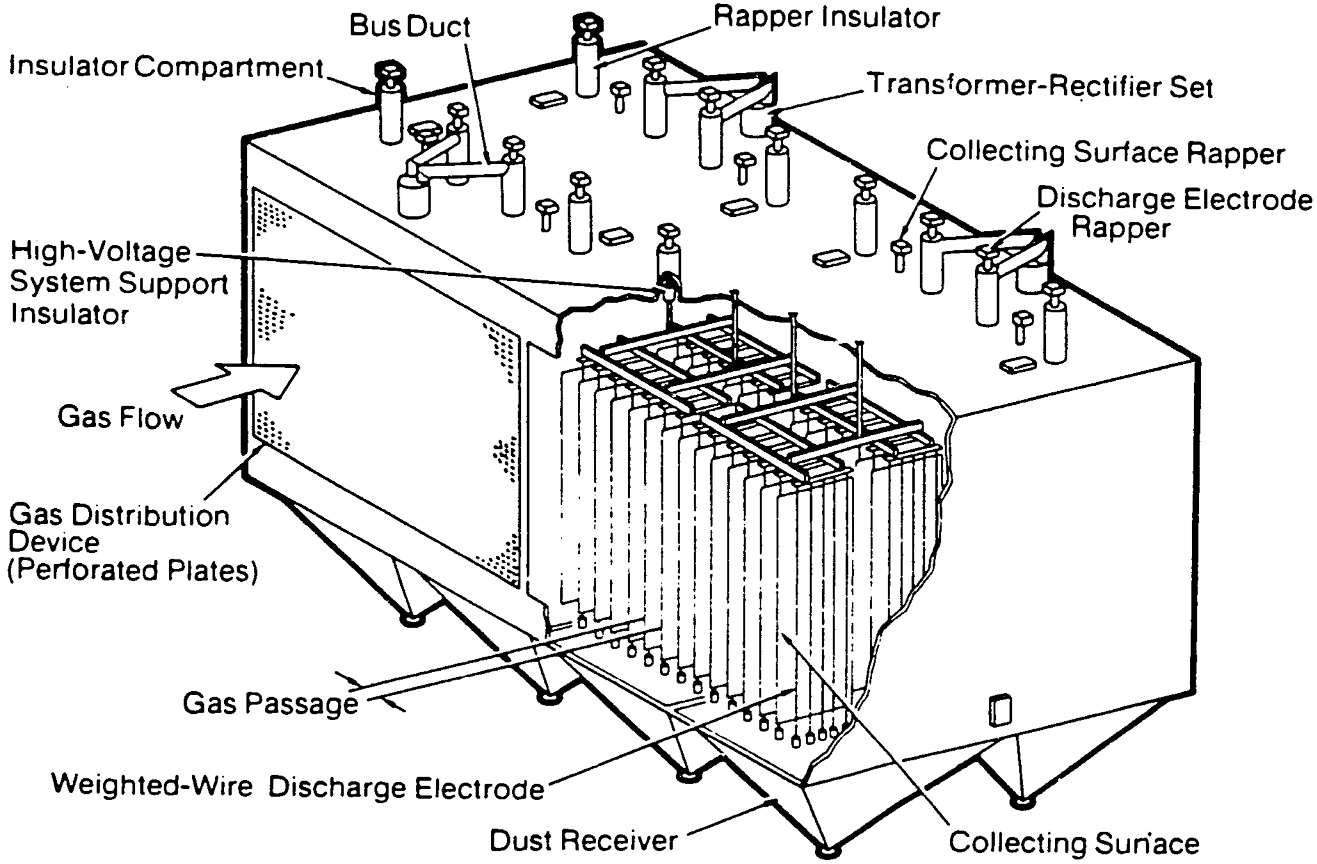


Figure 5-23 Typical Hopper and Vertical Shaft Air Heater Configuration



Combustion
Fossil Power Systems
Combustion Eng., Inc.

Figure 5-24 Typical Weighted Wire Precipitator

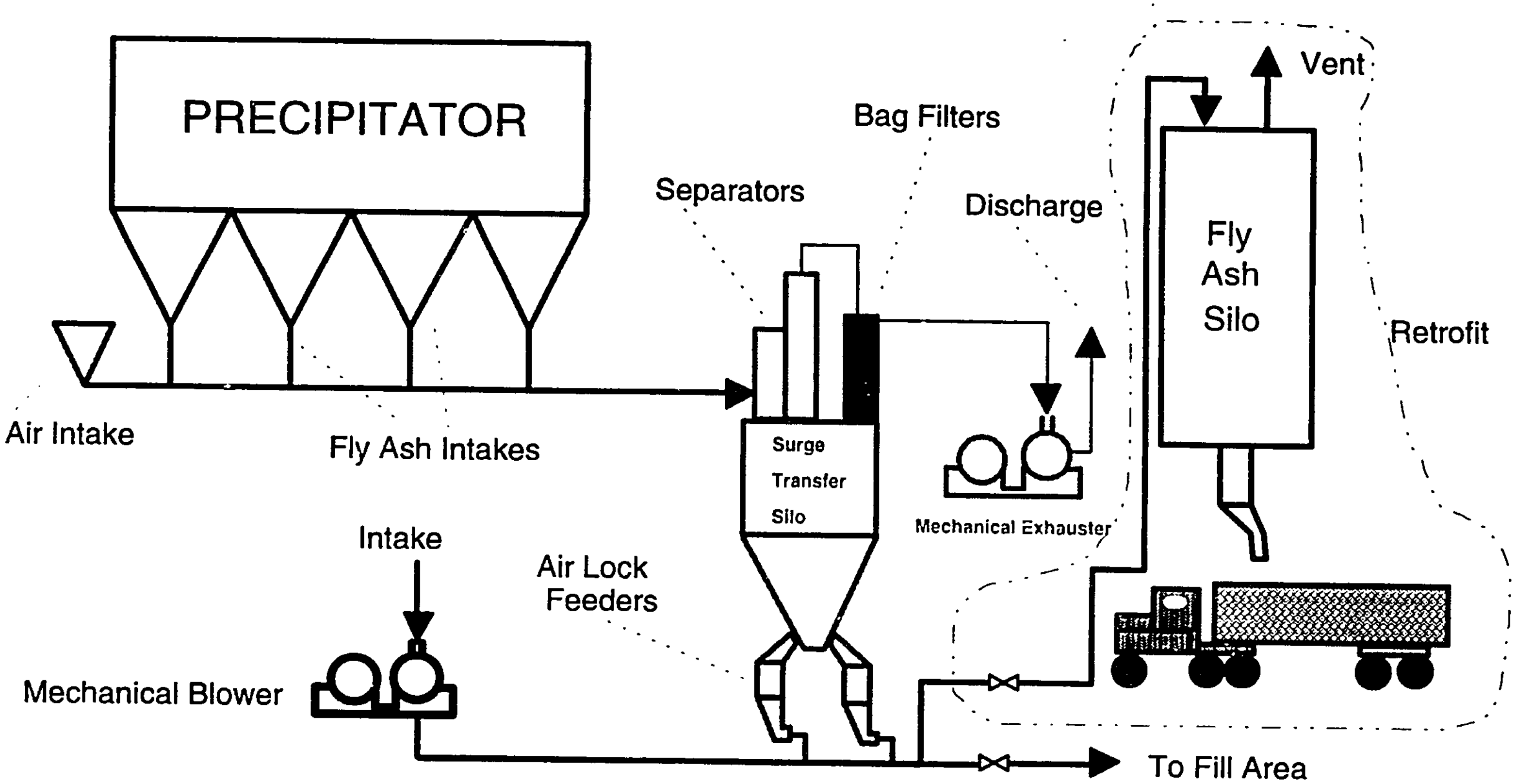


Figure 5-25 Fly Ash Vacuum and Pressure Conveyor

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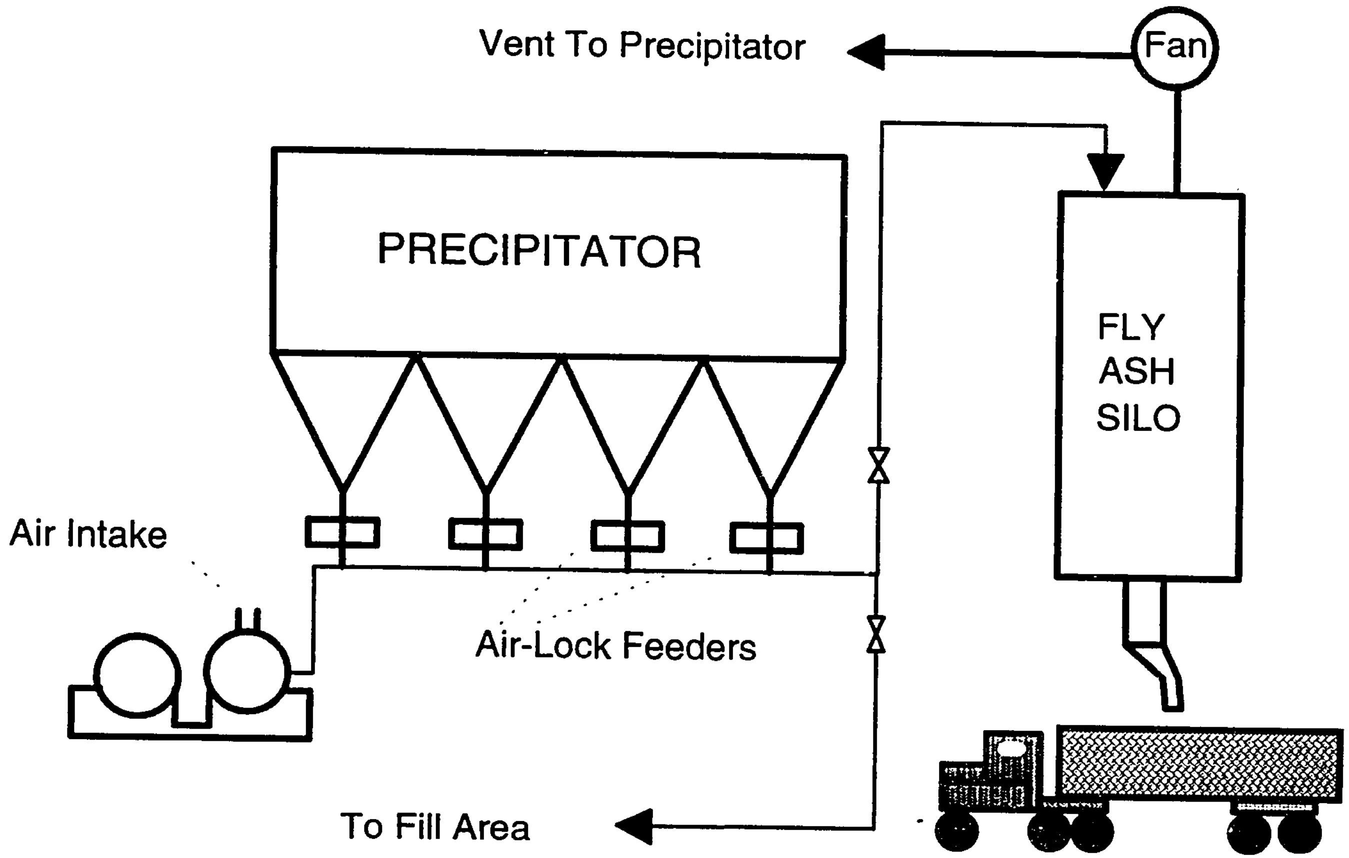


Figure 5-26 Fly Ash Pneumatic Pressure Conveyor

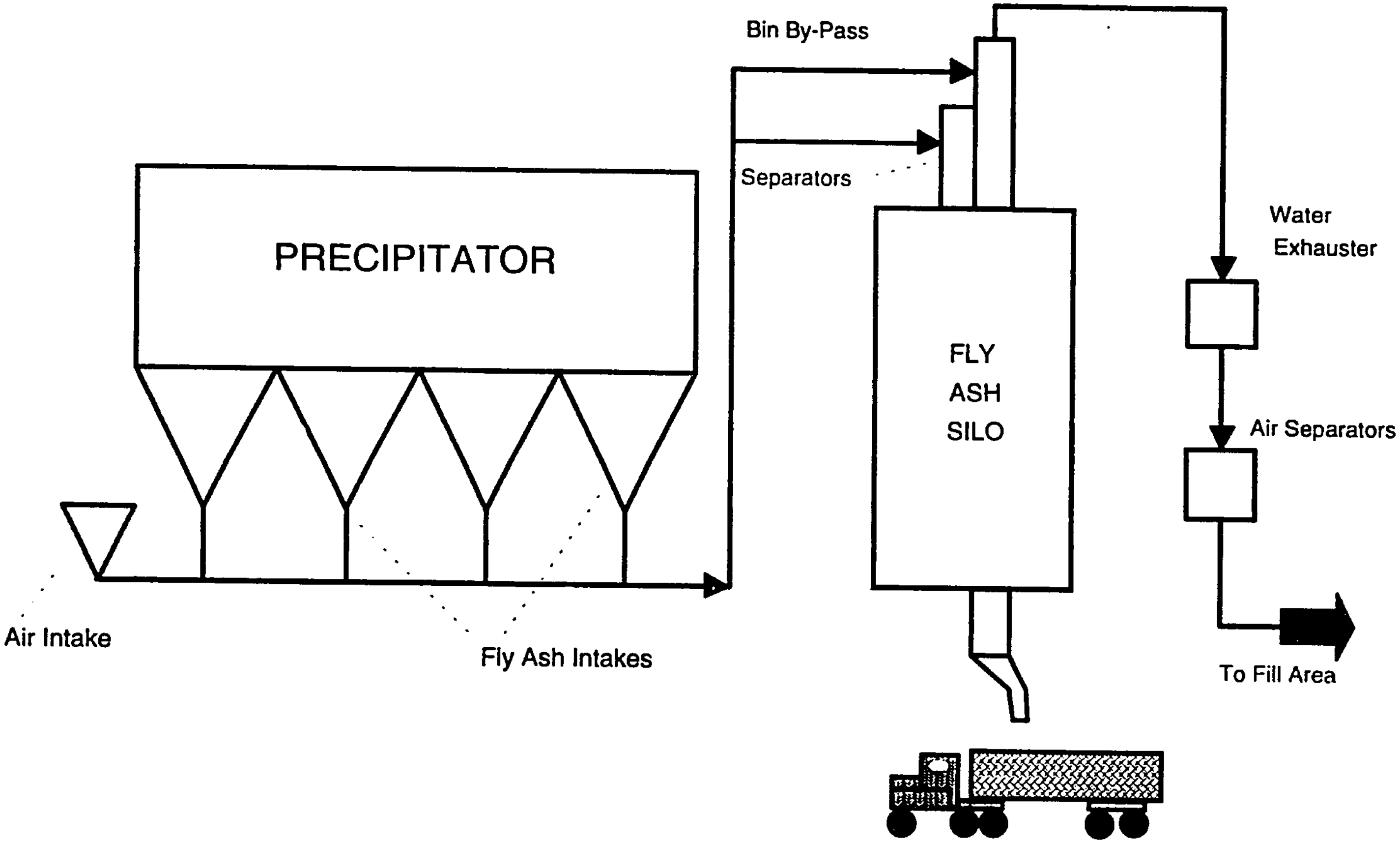


Figure 5-27 Fly Ash Hydraulic Vacuum Conveyor

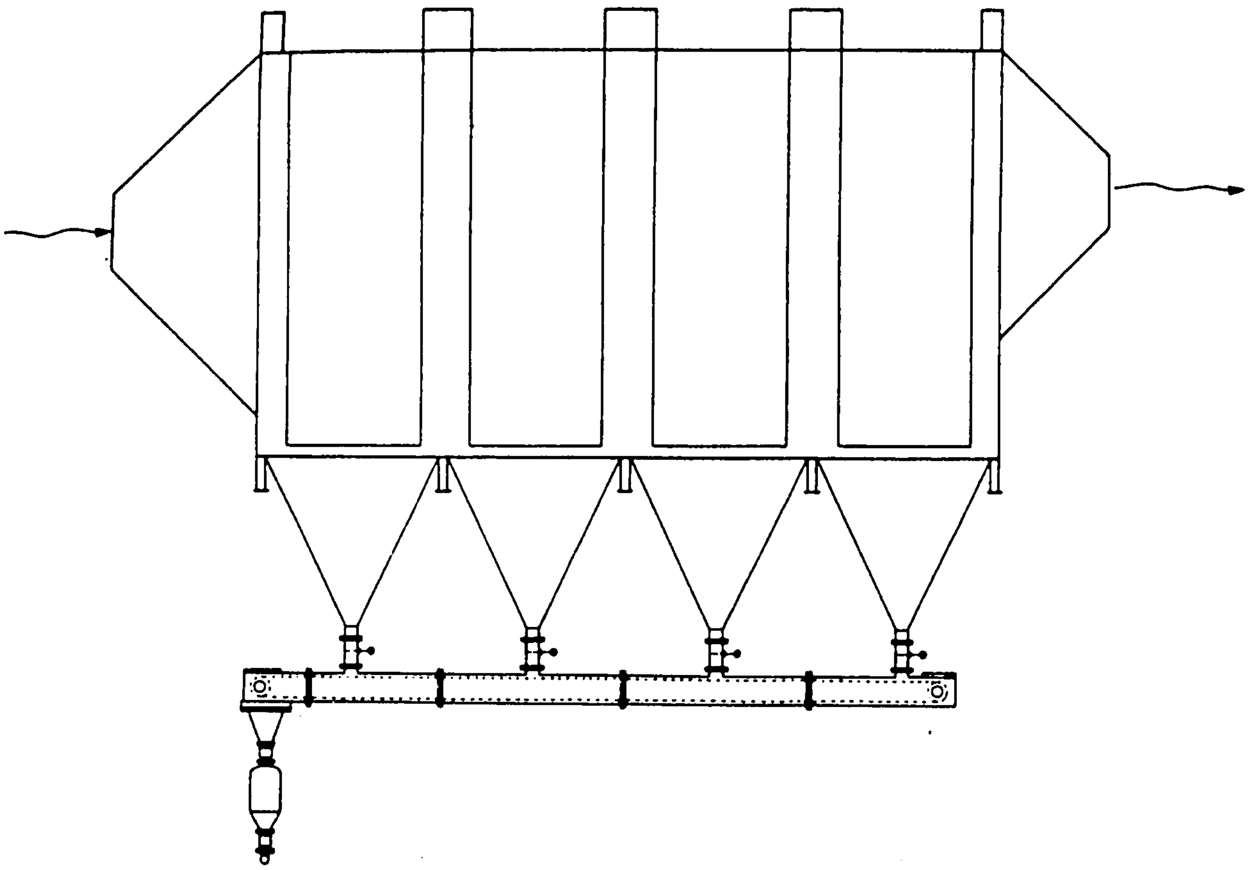


Figure 5-28 Combined Mechanical/Pneumatic Transport System for Continuous Removal of Precipitated Fly Ash

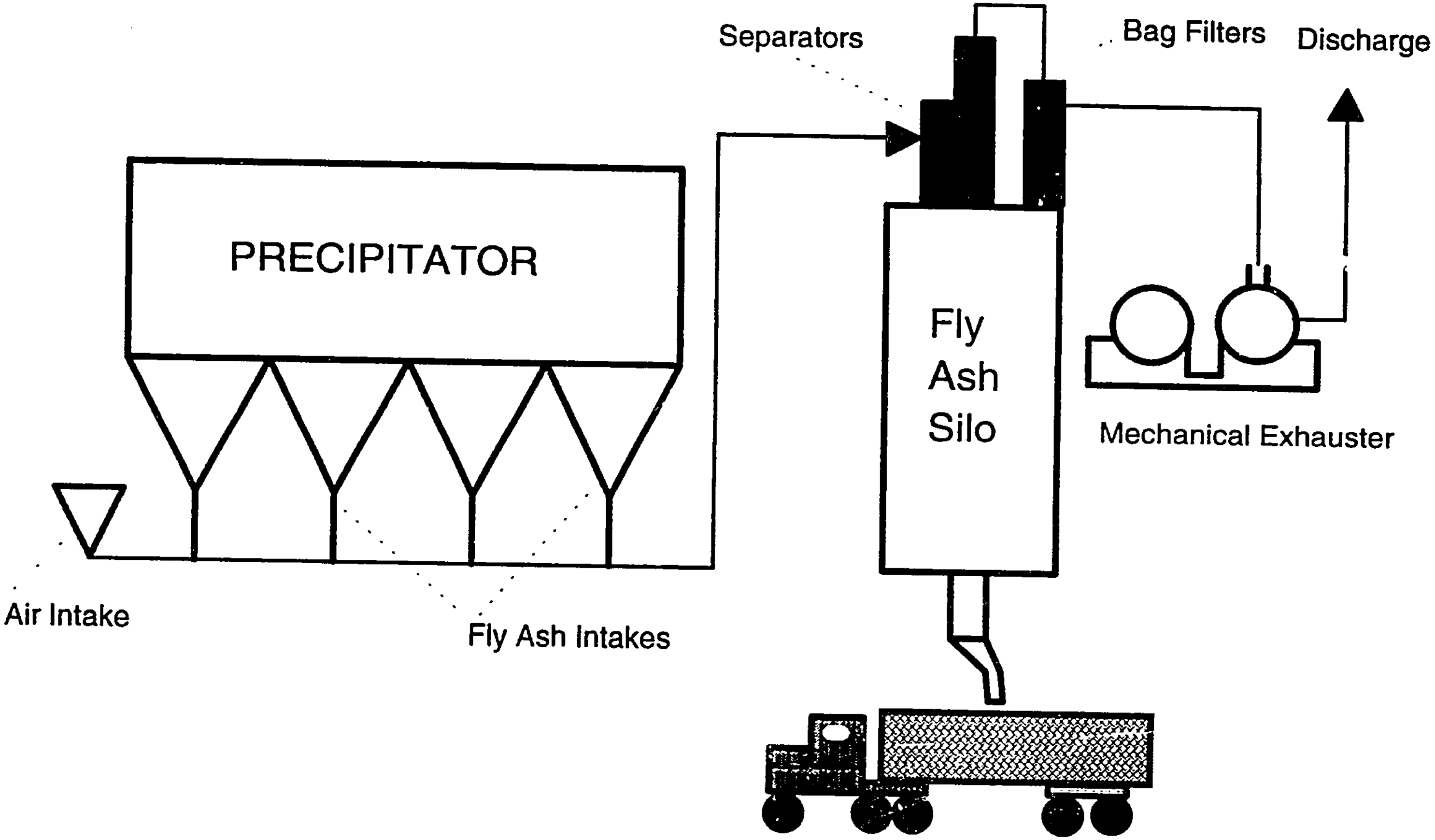


Figure 5-29 Fly Ash Pneumatic Conveyor

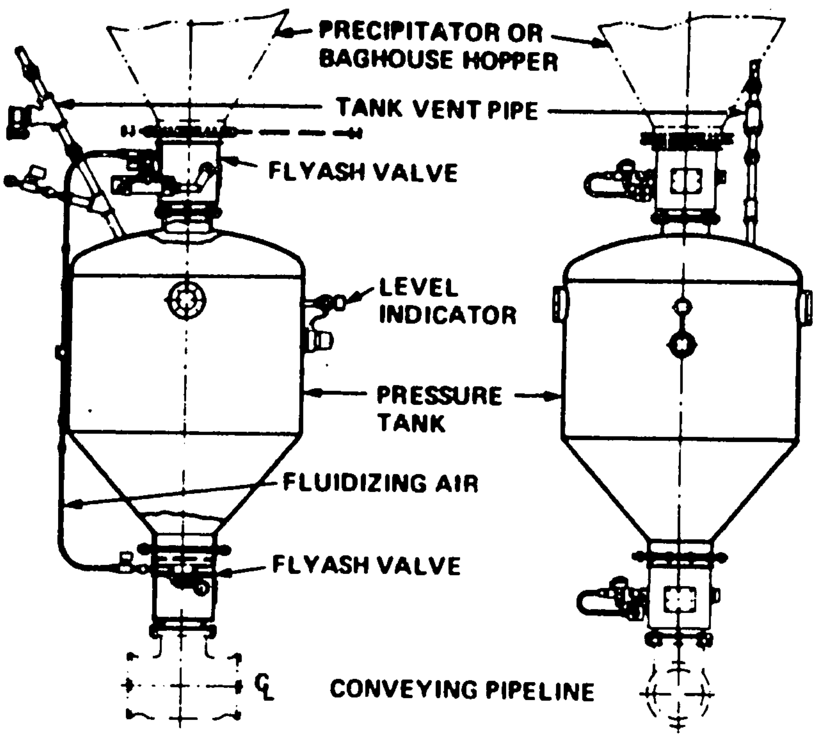


Figure 5-30 Positive Pressure Air-Lock Feeder

(disc-type gate vacuum removal system)

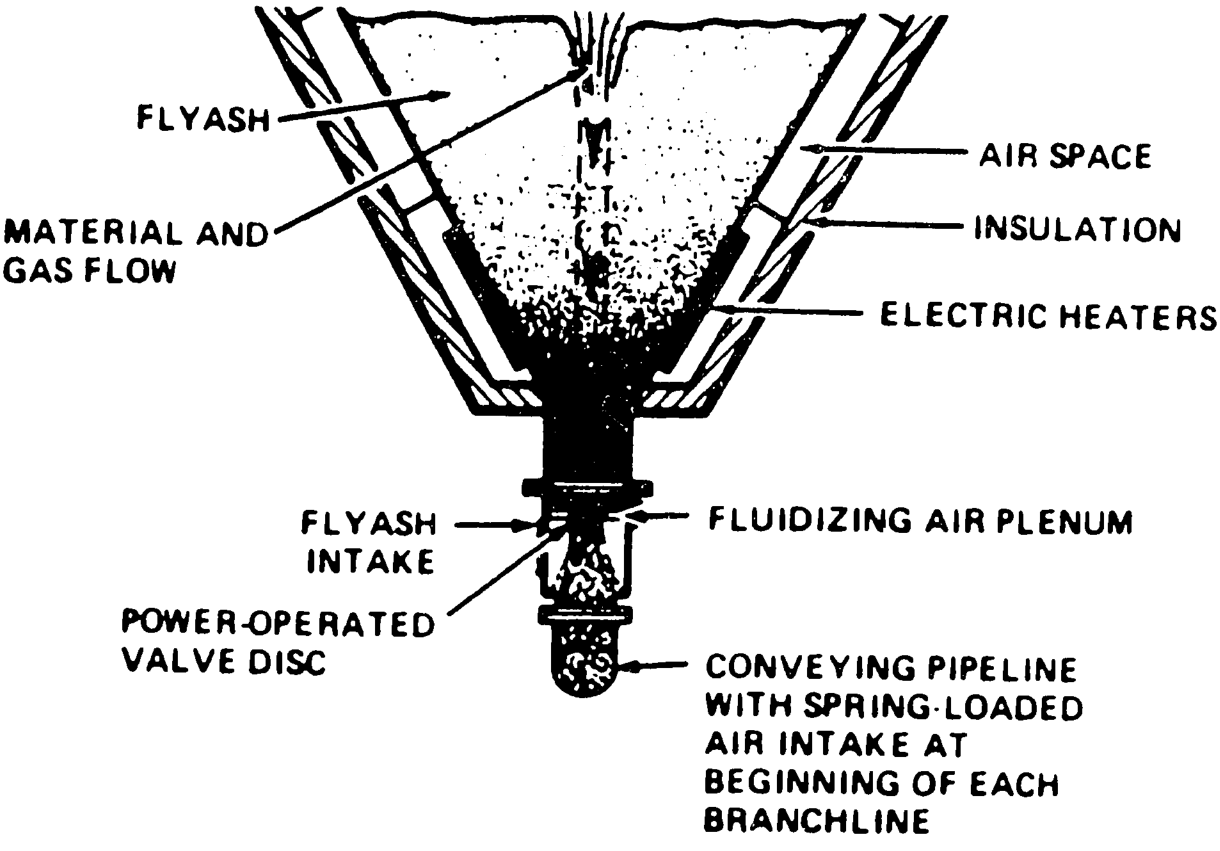


Figure 5-31 Fly Ash Hopper with Fly Ash Intake

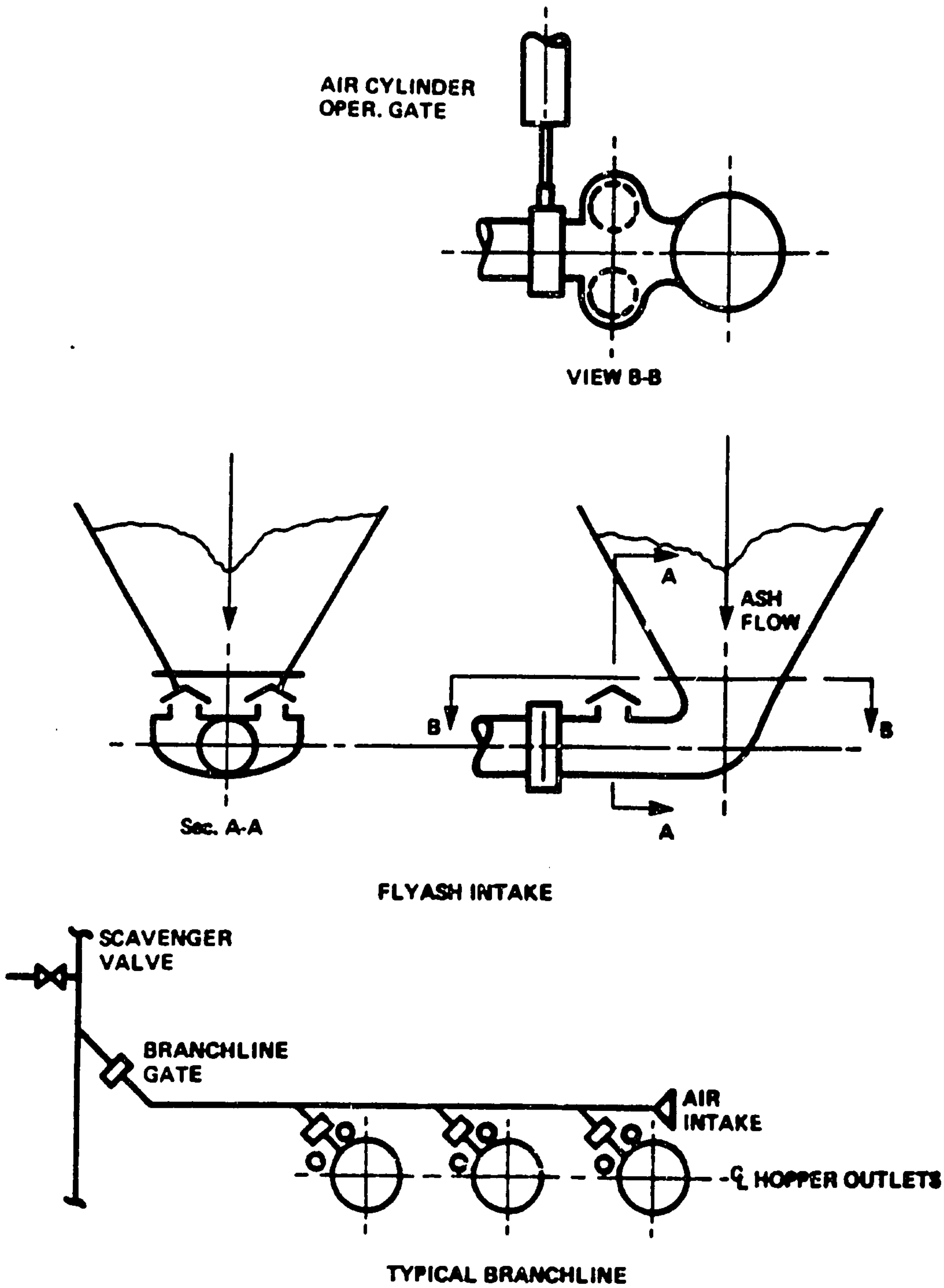


Figure 5-32 Fly Ash Intakes with Shut-Off Gates in Horizontal Lines

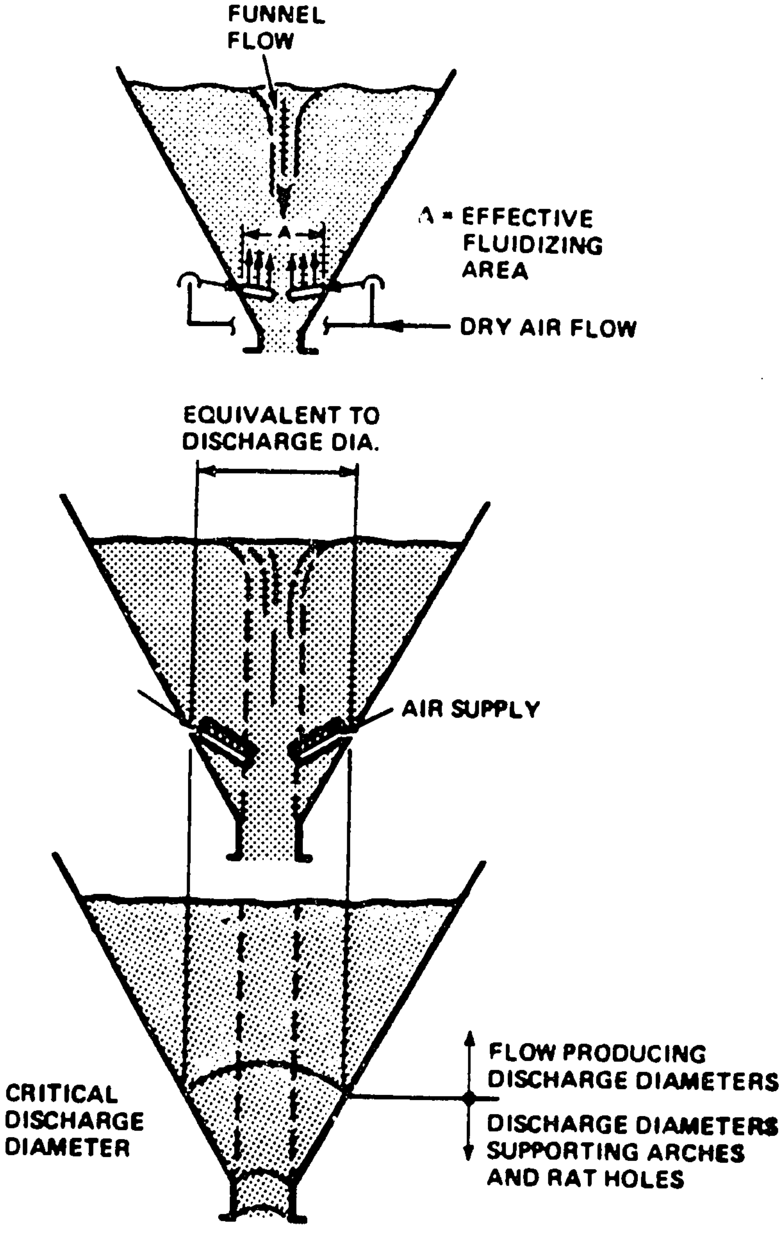


Figure 5-33 Fly Ash Fluidizers vs Discharge Diameters

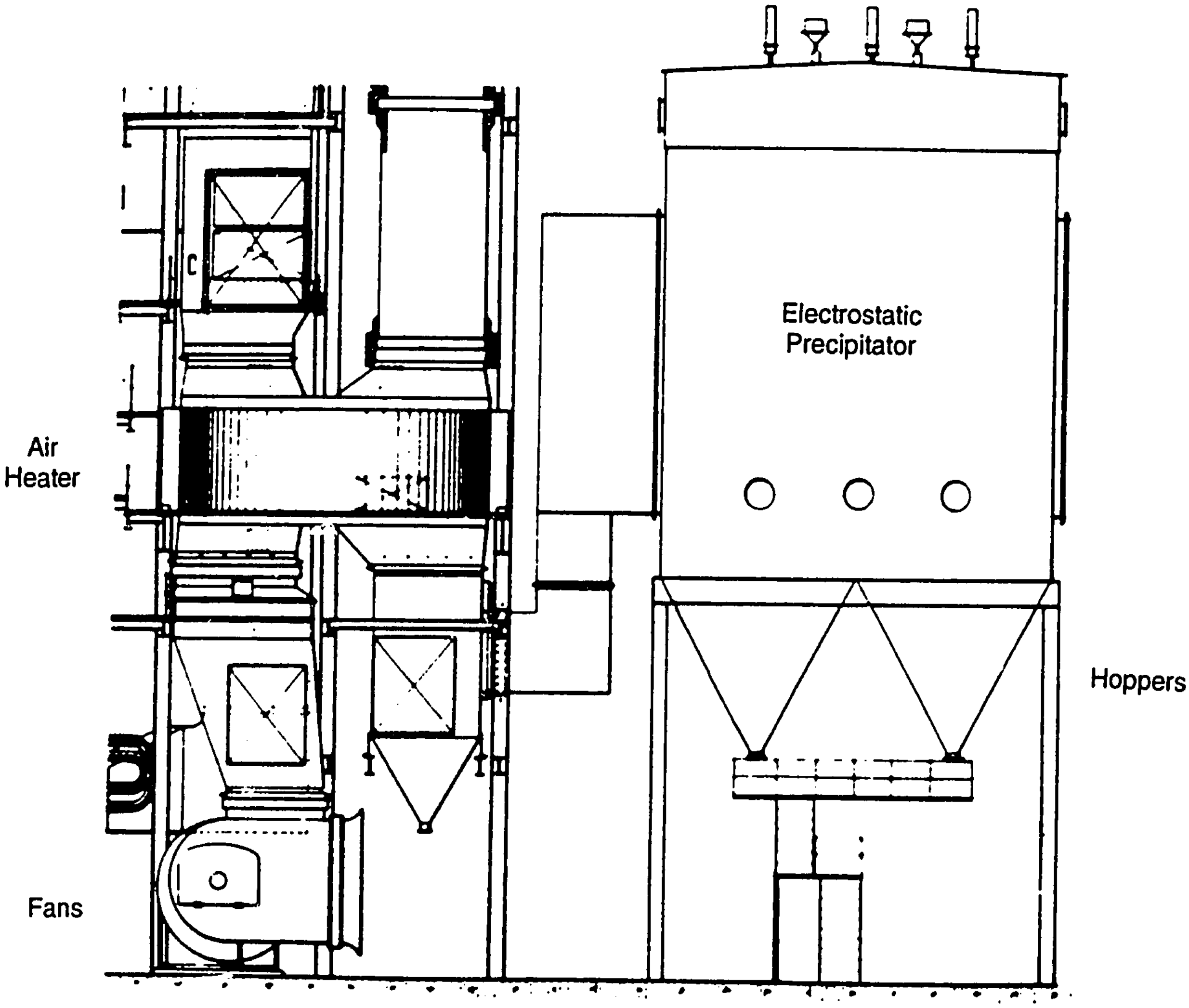
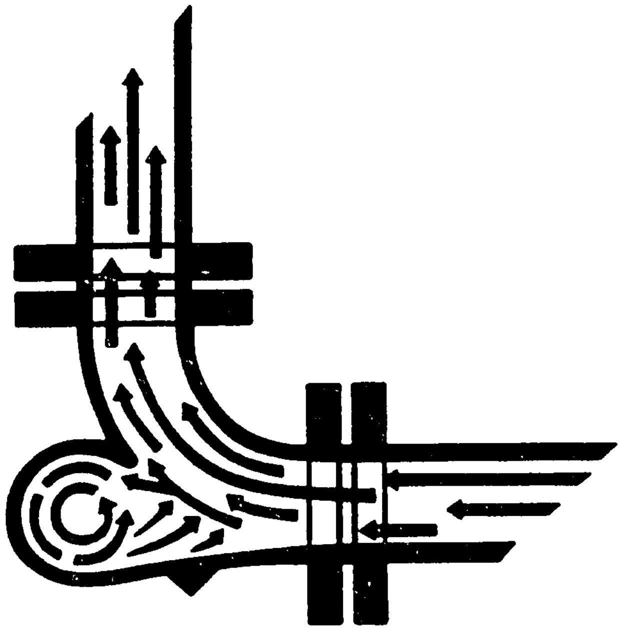


Figure 5-34 Location of Forced Draft and Primary Air Fan Inlets Near Precipitator Hoppers



HammerTek Vortice Ell® Elbow

Typical Materials

Aluminum Socket Weld/Flanged	ASTM SC-6-4C
Cast Iron Flanged Only	ASTM A-48-74 Class 25-30
Carbon Steel Socket Weld/Flanged	ASTM A-216 Grade WC-B
Stainless Steel 304 Socket Weld/Flanged	ASTM A-743 Grade CF-8
Stainless Steel 316 Socket Weld/Flanged	ASTM A-743 Grade CF-8M
HammerLast™* Flanged Only	ASTM A-48-74 Class 50-60 Acicular
Ductile** Socket Only	ASTM A-897-90 Grade 5

*Pipe size only; **Tube size only.
Note: 125 lb. flanges to ANSI specifications are standard; other sizes by request

HammerTek Corp.
Landisville, PA., USA

Figure 5-35 Recessed Entry Elbow

APPENDIX A

Trip Report To Romania – Ash Disposal

August 9, 1993

TRIP REPORT

Trip to Bucharest, Romania
Week of July 19 through 23, 1993
Romanian Energy and Electric (RENEL) Power
Project No.: 21978-000

Report By: Phil M Chopan
Environmental Technology
Bechtel Environmental Inc. (BEI)
50 Beale Street, SF, CA, 94119-3965
Tel. (415) 768-6305, Fax.-7299

Copies to : Joseph H Westsik
Files

SCOPE

Under US AID Contract, Bechtel is to respond to specific requests from RENEL for technical assistance in the areas critical to improving operational efficiency of Romanian power generating plants. As an initial step in identifying specific areas of concern, a trip was arranged for the Bechtel technical team to meet with the RENEL personnel and visit one or two typical plant sites. The Bechtel technical team on this trip consisted of Roy, Murrin; Bob, Steigerwald; Joe, Westsik; and myself. Joe was the task leader.

The scope of my trip was to collect information in my area of specialty which relates to ash storage, containment, and reclamation. The other members of the trip were to address issues such as ash handling, corrosion, cavitation, and fuel combustion efficiencies.

This report includes only what was observed and the pertinent data provided to us by the RENEL personnel; no sampling or analyses were conducted during the trip. This trip report, together with the trip reports from the other specialists, will be used to develop a Technical Report under the Romanian Task R-1 (Generating System Efficiency). The pertinent site data, conclusions, and recommendations will be included in the Technical Report to be issued later.

BUCHAREST MEETING

On Monday and Tuesday (July 19 and 20) we met with RENEL Technical Director, Ing. Ion Barbulescu and a group of his technical staff representing RENEL, Institute of Power Studies and Design (ISPE), and the Energy Research and Modernizing Institute (ICEMENERG) The following paragraphs present a summary of my

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discussion with the members of the meeting party concerning the subject of the ash storage/reclamation. Bechtel had previously faxed RENEL sixteen specific questions on ash storage and reclamation. These questions were also discussed as described below. RENEL written response to these specific questions are presented in Attachment 1 to this trip report.

The ash generated at the coal-firing power plants in Romania are generally disposed off as ash piles which take up considerable amount of land at or adjacent to the plant. The size of each ash storage area varies depending on the plant operation but historically it has been on the order of 10 to 170 hectares (25 to 420 acres). The height of the piles is on the order of 20 to 40 meters (65 to 130 feet). Some of these storage areas are near capacity and land acquisition for future ash piles is very difficult or impossible because of recent land restrictions and reluctance of land owners to sell or lease their land for ash storage. Reclamation of the existing ash piles has been successfully tried in limited areas. However, such reclamation has been costly. Furthermore, the reclaimed ash piles cannot be exchanged with the adjacent farm lands for storage of future ash because farmers are reluctant to accept the exchange.

Approximately 20 coal-firing power plants are currently operating in various counties of Romania, all have electrostatic precipitators. The ash generated at these plants is approximately 10 to 15 million tons per year of which only about one percent (150,000 tons per year) could be marketed for industrial use. The use of fly ash has been limited to mainly the following industries:

cement/concrete plants,
brick kilns,
lime kilns,
drilling mud production, and
construction.

The use of ash in construction industry (as fill material) is generally limited by the transportation cost over a distance of approximately 20 Kilometers (12.5 miles). Attempts to find more industrial use for the ash has been unsuccessful. Ash is not returned to the coal mines for a variety of reasons including distance, lack of demand, and/or absence of dedicated transportation systems.

The ash is generally mixed with water on a 10: 1 weight ratio (water: ash), and the resulting mix (slurry) is pumped to the storage area (ash piles). Only about 8 percent of the water is recycled mainly because of drainage loss; the ash is relatively permeable and the storage area has no lining. The ash in these piles is generally cohesionless with particle size in the range of fine sandy silts (fine sand: 0.1 to 5 mm; silt: 0.1 to 0.002 mm;). The dry unit weight of the ash is on the order of 0.75 tons per cubic meters (50 pounds per cubic feet). Large pumps and steel pipes are used for pumping the ash from the plant to the storage area. The diameter of these pipes is on the order of 25 to 50 centimeters (10 to 20 inches).

The slurry is dumped in the storage area which is confined by perimeter berms roughly 3 to 6 meters (10 to 20 feet) high. The berms are generally composed of soil materials with slopes on the order of 1:3 (vertical: horizontal). Once the slurry level is near the top of the berm and after the slurry is drained, another ring of perimeter berm is constructed on top of the previous berms and the storage operation continues. Several berms may be built on top of one another in an almost pyramid fashion until the storage capacity is reached; as dictated by a variety of factors including pumping capacity to lift the slurry to the top of the final berm, slope stability of individual berms, and slope stability of the entire ash pile. For an overall slope of 1: 5 (vertical: horizontal) RENEL has reported a safety factor of 1.2 to 1.3 (based on Fellenius method of analysis) for the storage operation. Only one slope failure has been reported at the Turceni Thermal Power Plant which occurred in April 8, 1993 (See Attachment 1 to this trip report).

Any leachate (water or liquid) collected from the piles, if not recycled, is disposed at surface waters without any special treatment. The leachate is not monitored for chemical makeup. The typical chemical content of the ash is provided in Attachment 1. Based on the RENEL response, the ash contains no significant amount (nil) of toxic elements, carcinogenic substances, or other chemicals of health concern. The only radioactive material in the ash is Ra 226 which may be in the range of 3.25 to 8.10 pico Curie per gram. According to one member of the ICEMENERG Institute, the levels of radioactivity in coal is about 10 pico Curie per gram, consisting of Ra 226 and K^{40}.

Mr. Barbulescu emphasized that considering the restrictions in obtaining land for future ash piles, RENEL needs technical assistace and recommendations on measures to accomplish the following:

- reduce ash generation,
- improve ash handling,
- reduce land use by improving ash storage efficiency,
- enhance ash pile reclamation, and
- properly contain the ash.

Mr. Barbulescu suggested that we visit two power plants after conclusion of the meeting: Craiova 1, and Brazi power plants. He indicated that these plants are neither typical nor the worst plants. However, they do have a fair amount of problems discussed in the meeting and their proximity to Bucharest would accommodate our schedule. Craiova Plant operates on coal and has substantial problems with ash storage. Brazi Plant does not have ash storage problems as it is not a coal-firing plant, but it does have substantial problems associated with corrosion, cavitation of water feed pumps, fuel combustion efficiency, sulfur removal technology, and breakage of some oil coolers (for details of Brazi problems see trip reports by the other specialists). The meeting was concluded on Tuesday afternoon on July 20.

CRAIOVA POWER PLANT

On Wednesday July 21, we drove from Bucharest to the Craiova 1 coal-fired power plant which is located approximately 250 Kilometers west of Bucharest. It took about 5 hours to drive on a two-lane highway which cuts across the Romanian low lying plains and passes through several small towns and farm lands. The plant is situated outside the City of Craiova. We met with the Plant director and his staff who provided us with the information summarized below.

Craiova 1 is a 1000 mega-watt power plant consisting of 8 units. It has over six turbines and ten boilers. Four of the boilers are large, each with a capacity of 510 tons per hour. The capacity of the smaller boilers is on the order of 300 tons per hour. The first boiler started operation in 1964. The lignite used at the plant burns at approximately 1200 to 1700 Kilo calories per kilogram. The chemical breakdown of the coal is typically as follows:

Constituent	Weight Percentage
Ash	29
Sulfur	0.8
Carbon	19
Hydrogene	1
Moisture	41
Others ???	9.2
Total	100

The analytical data for the ash, measured in 1989, are presented in Table A of Attachment 1. The annual production of ash at the plant is approximately 3 million tons per year. The captured dry ash is only about 24,000 tons per year. Less than about 20 percent of the ash consists of the economizer ash and bottom ash. The particle sizes of the bottom ash and the economizer ash are mostly small and mostly within size ranges of sands (0.1 to 5 millimeters), although gravel size particles may be encountered occasionally. Approximately 99 to 96 percent of the ash has particle size smaller than 0.2 mm. The economizer ash, bottom ash and fly ash are generally mixed together with water and made into a slurry which is then pumped to the ash storage area. Steel pipes with an approximate diameter of 30 centimeters (12 inches) are used for pumping the slurry to the storage area which is located approximately 2 kilometers (1.25 miles) away from the plant site.

Four pumping stations are used to pump the slurry approximately 2 kilometers away and 40 meters (130 feet) high. Each station has four large capacity pumps two of which are operating and the other two are kept for spare. The slurry is generally made with a 10: 1 ratio by weight (water: ash). Acid is added to the water to remove deposits from inside the pipes. Attempts have been made to reduce the ratio of water in order to economize in pumping volume, water usage, and storage room. However, these attempts have not been successful mainly because of problems associated with particle segregation in the pipes and pumping difficulties. They have not tried adding surfactants or fluegulating agents to the slurry, or separating the bottom ash before pumping the slurry.

Coal is brought in the plant by dedicated rail cars that open at the bottom. The 60-ton capacity rail cars are not lined or covered at the top. The rail cars return to the coal mines empty. Ash is not sent back to the mines because the miners do not want it. Strip mining is used for coal mining and land reclamation is required in the specifications. However, land reclamation in the mines is not strictly ~~followed~~ and, therefor, use of the ash as reclamation material is not much in demand.

The ash storage near the plant ~~site~~ began in 1964. The closest available low lying land (river bed?) was selected for the ash storage area about 2 kilometers from the plant. The current occupied storage area is approximately 136 hectares (336 acres). It is projected that within the next 5 years the ash storage will take up an area of over 175 hectares (432 acres) which is the full storage capacity of the Criova power plant. Therefore, the plant operation would have to shut down in 5 years unless new land is aquired or the ash disposal/storage problem is resolved. Acquisition of new land seems very unlikely. Thus, the ash storage problem has to be resolved and implemented before the end of the five year period.

After discussing the above issues, we visited the plant facilities and drove up on a dirt road to see the ash storage area. The ash piles and berms are sometimes indistinguishable as the berms are covered with dust (ash). Grab samples from the berm in several locations appeared to be clayey silt with some fine sands. Grab samples from the ash appeared like silt with some fine sands. Both the berm material and the ash deposits seemed to be relatively permeable and easy to drain. All the ash piles we saw were well drained and relatively or completely dry. We could not see the actual wet disposal point where slurry is dumped off the pipes. It was explained to us that the actual dump point looks like a shallow pond where the water drains or it is pumped back for recycling.

I could not see any drainage blankets on the slopes of the berms. It seemed that most of the water would permeate through and very little water could be collected even if there was a drainage blanket. There were no dust control measures and we were told that dust clouds are common on windy days. Dust has been a source of complaints from the residents in the surrounding area. Traffic with light-weight vehicles is possible on the dry embankment. Four-wheel, light-weight vehicles could be tried on the dry ash deposits; almost like driving on sand dunes. The height of the ash piles we visited was on the order of 30 meters (100 feet). However, these piles were still being used and could go higher. We were told that the pumping capacity is a major factor in determining the final height of the piles. Stage pumping is not used to increase the height limits for the piles.

We then visited an experimental plot of land where the ash pile was reclaimed for agriculture. The plot of land was probably about 0.5 hectares (1.2 acres) situated on top of an ash pile approximately 40 meters (130 feet) above the surrounding grade. The plot had healthy crops of cotton, peanuts, strawberries, tobacco, and tomatoes; fruit-bearing trees including apricots, and apples; grape vines; and other shrubberies. We were told that the only reclamation work performed on the ash pile consisted of adding fertilizers directly to the ash near the surface. All the crops and trees were grown directly on the ash pile with no top soil. The wonderful garden appeared like the reclamation project was very successful. However, there were several problems. The land was too high up from the irrigation water source and the water had to be pumped at additional costs. Most of the irrigation water was wasted by rapid drainage into the ash pile as there was no liner or relatively impermeable soil layer to retain the moisture. Also, farmers were reluctant to try cultivation because they were suspicious of possible radioactivity in the ash and possible long-term carcinogenic effect through the agricultural products. We tried some of the fruits and the left the site.

BRAZI POWER PLANT

On Wednesday July 21, we drove from Bucharest to the Brazi Plant which is a fuel-burning power plant situated in the northern mountainous region of the country. Because the winding two-lane highway runs through hills and small resort areas, it took approximately three hours to drive to the plant even through it is only about 80 Kilometers north of Bucharest. We met with the plant director, Ing. Dumitrescu Mircea and visited the plant.

Mr. Mircea explained that this plant has been operating since 1961. Several units have been added to it since. The plant operates on fuel oil, on gas, or a mixture of both depending on fuel availability. high sulfur content has been a major source of problem at this plant. The sulfur content of fuel oil from the Romanian crude oil is approximately 1 to 2 percent. However, since 1982 fuel oil available to the plant has had higher sulfur contents on the order of 3.5 percent. Because of short fuel supply, some of the units which are designed to operate only on gas have had to operate on fuel oil intermittently. This has compounded problems associated with high sulfur contents, corrosion, and cavitation. After the meeting, we visited the plant facilities and left the site. Since the Brazi Plant operates on fuel, there are no ash pile problems at this site. Therefore, this plant is not discussed further in my trip report which is concerned with ash pile storage problems. Detail discussion of this plant and its specific problems may be found in trip reports by the other members of the trip.

ATTACHMENT 1
to Appendix A

Bechtel Initial Questions on Ash Storage and Reclamination

and

RENEL Response

Bechtel's Initial Qestions on Ash Storage and Reclamation (Soil Reclamation and Remediation Studies)

1 - Please provide the following information on the height (H) of each ash pile and the size of the area (A) typically covered by each pile:

Typical values of A and H
Maximum values of A and H
Minimum values of A and H

2 - What are the engineering properties of the ash within the ash piles in general? Please provide typical values, maximum and minimum values. Include the following information as much as possible:

Dry unit weight (W)
Saturated unit weight (Ws)
Moisture content (M)
Specific gravity (S)
Cohesion or shear strength (C)
Friction angle (F)
Angle of repose (Ar)
Size classification and/or gradation (G)

3 - What is the chemical make up of the ash in the piles in general? Please provide typical values, maximum, and minimum values. Include the following information as much as possible:

Toxic elements
Carcinogenic substance
Radioactive material
Other chemicals of health concern

4 - What size equipment, if any, can be used on top of these piles? Please indicate small vehicles, 4-wheel vehicles, rubber-tired vehicles, small trucks, heavy equipment etc.

5 - What are the possibilities of sampling these ash piles and analysis for chemical and physical properties?

6 - How old are these piles? Give rough estimate and range.

7 - Is any historical information available on any slope failures and /or sloughing? Please explain.

8 - What are the engineering properties of the berms containing these piles? Please provide geotechnical information similar to item 2 above.

9 - What is the safety factor against slope failure through the base of or throgh the mass of these berms?

10 - What is the overall safety factor against gross slope failure of the entire ash pile inclusive of one or more berms?

11 - What is the current production rate of ash in tons per year per plant? Is this rate to continue?

12 - Has the ash ever been stabilized chemically? Please explain and provide details.

13 - What are the past and present practices of ash stabilization in the country?

14 - What are the past and present practices of ash pile reclamation in the country?

15 - Are annual precipitation data available for each location for the past 40 years? Please indicate the source address and phone number.

16 - Are seismic data available for the different localities? Please indicate the source address and phone number.

SOIL RECLAMATION AND REMEDIATION STUDIES

The answers given in the hereby material refer to 6 thermal power plants, namely:
1. Turceni thermal power plant
2. Rovinari thermal power plant
3. Isalnita thermal power plant
4. Mintia-Deva thermal power plant
5. Doicesti thermal power plant
6. Craiova II thermal power plant.

Q1: Please provide the following information on the height (H) of each ash pile and the size of the area (A) typically covered by each pile.

A1: The average values of the heights (H) and the size of the areas (A) covered by the ash piles for each ash storage are as it follows:

Denomination of the ash pile storage	Area [ha²]	Height [m]	Remarks
TURCENI T.P.P.			
Valea Ceplea	161.7	0.00	Is to be reused.
Storage No.2	169.0	8.5	In operation.
ROVINARI T.P.P.			
Cicani West	65.4	15.0	10% still available for storage.
Cicani East	66.0	17.0	Ditto.
Beteregea	118.0	0.9	In operation.
ISALNITA T.P.P.			
Right-bank storage	145.0	26.0	In operation.
Left-hand storage	136.0	32.0	In operation
MINTIA-DEVA T.P.P.			
Mures-right-bank	63.0	40.0	In operation.
Bejan Valley	87.0	26.0	In operation.
DOICESTI T.P.P.			
Storage No.1	12	38.0	Exhausted.
Storage No.2	25	42.0	Exhausted.
Storage No.3	10	28.0	Still to be used.
Poiana Mare	48	29.0	In operation.
Storage No.5	18	0.00	Under construction
CRAIOVA II T.P.P.			
Valea Manastirii	120	30.0	In operation.

Q2: What are the engineering properties of the ash within the ash piles in general?....

A2: The physical properties of the slag and ash within the ash piles are the following:

Specific gravity (S):	$S = 2 \div 2.15$ t/m³
Saturated unit weight (γ_s): γ_s	$= 1.3 \div 1.5$ t/m³
Dry unit weight (γ):	$\gamma = 0.7 \div 0.8$ t/m³
Shear strength (Ø):	$Ø = 28 \div 35°$
Cohesion (C):	$C = 0 \div 0.3$ t/m²

Size classification (example):

Grain size d [mm]	Percentage [%]
0.0002 < d < 0.005	4 ÷ 16
0.005 < d < 0.05	32 ÷ 50
0.05 < d < 0.25	26 ÷ 44
0.25 < d < 0.5	6 ÷ 16
0.5 < d < 2	2 ÷ 8

Q3: What is the chemical make up of the ash in the piles in general?

A3: Within RENEL power plants, the ash in the piles has not been treated chemically.
Typical values are - as it follows:

Toxic elements:	nil
Carcinogenic substances:	nil
Radioactive material:	Ra 226: 5.63 ± 2.38 pCi/g
Other chemicals of health concern:	nil

Q4: What size of equipment, if any, can be used on the top of these piles?

A4: On the top of the pile banks, traffic is practicable. Width: 3.5 m. Usually after storage termination on the top dry-areas of ash piles, traffic is practised normally.

Q5: What are the possibilities of sampling these ash piles and analysis for chemical and physical properties?

A5: The possibilities of sampling these piles are by excavation.

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Analysis for DEVA I.P.P. ash piles

Specific weight, g/c.cm	: 1.990
Al_2O_3, %	: 24.69
Fe_2O_3, %	: 5.67
CaO, %	: 1.65
MgO, %	: 0.22
Na_2O, %	: 2.25
K_2O, %	: 1.15
SiO_2, %	: 56.04
Calcinated residues	: 2.61

Q6: How old are these piles?

A6: Such ash piles are 3÷40 years old.

Q7: Is any historical information on any slope failures and/or sloughing?

A7: We know only about one event when the pile bank collapsed at Storage No. 2 from Turceni thermal power plant. It happened on the 3-th of April, 1993. The possible cause for such an event is the uneven filling of the storage, as well as the occurrence of a water layer of about 1 meters high which eroded from inside.

Q8: What are the engineering properties of the berms containing these piles?

A8: The berms are of circulation type.

Q9+10? What is the safety factor against slope failure through the base of or through the mass of these berms? What is the overall safety factor against gross slope failure of the entire ash pile inclusive of one or more berms?

A9+10: At an overall slope of 1:5, the safety factor (Fellenius) is of 1.2 ÷ 1.3 (for the storage in operation).

Q11: What is the current production rate of ash in tones per year, per plant? Is this rate to continue?

A11: RENEL power plants produce about 11,000,000 tons of ash per year. If the question refers to the capture capacity of the dry ash from electroprecipitators, then - for the 6 power plants equipped with dry ash capture and removal system - the current production rates are as it follows:

Isalnita power plant : 120,000 t/year
Mintia power plant : 162,000 t/year   Borzesti II:130,000t/y
Doicesti power plant : 100,000 t/year
Rovinari power plant : 234,000 t/year
Comanesti power plant : 54,000 t/year
T o t a l : 800,000 t/year

It is estimated that the dry ash capture capacities will be not extended further (lack of Clients).

Q12: Has the ash ever been stabilized chemically? Please explain and provide details?

A12: Slag and ash storaged hydraulically in piles have never been chemically treated. (Tests with carbide slurry have been carried

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out at lignite power plant).

Q13+14: What are the past and present practices of ash stabilization in the country? What are the past and present practices of ash pile reclamation in the country?

A13+14: During operation, in order to prevent ash blowing and spreading, the piles are moistured by spraying or silification (matter under investigation). After the termination and closing of the storage, the pile is covered with vegetal soil and returned to the agricultural circuit (partially, while a large part of the area is used for direct plantation on ash).

Q15: Are annual precipitation data available for each location for the past 40 years?

A15: All data regarding precipitation for each location and the past years can be obtained from the INSTITUTUL NATIONAL DE METEOROLOGIE SI HIDROLOGIE, Bucharest, Romania Telephone No. 637.70.10.

Q16: Are seismic data available for the different localities?

A16: Seismic data are available at INSTITUTUL DE GEOLOGIE SI GEOFIZICA, Bucharest, Romania , Telephone No. 665.34.90

ANALIZA CENUSN

TABLE A – ASH TEST FOR TYPE B FUEL

DENOMINATION	SYMBOL	U M	STAS* LIMITING VALUE	MEASURED VALUES			
				MIN.	DATE	MAX.	DATE
Wetness	W	%	max. 1	0.05	April 1989	0.5	Oct. 1989
Remainder on 0.2 sieve	R02	%	max. 10	1.1	April [illegible]	11.8	Mar. 1990
Calcination Loss	PC	%	max. 3	0.[illegible]	Oct. [illegible]	1.4	Jan. 1989
Activity Number	F_{zv}	%	min. 75	77.5	May [illegible]	83.0	Aug. 1989
Silicon Dioxide	SiO_2	%	min. 49	41.9	Nov. [illegible]	4[illegible].8	[illegible] 1989
Magnesium Oxide	MgO	%	max. 4	2.0	Jan. [illegible]	4.0	Mar. 1989
Calcium Oxide	CaO	%	min. 7	6.7	Jan. [illegible]	10.[illegible]	Nov. 1989
Iron Trioxide	Fe_2O_3	%	min. 9	8.9	A[illegible]	18.7	May 1989
Aluminium Oxide	Al_2O_3	%	min. 20	18.8	Ma[illegible]	25.2	April 1989
Sulphur Trioxide	SO_3	%	max. 2	1.0	Jan. 1989	3.1	Nov. 1989

Fusion Temperature : 1120°C

Melt Temperature : 1150°C

Flow Temperature : 1185°C

REFERENCE: Provided by the staff from CRIOVA 1 Power Plant, 7/21/93.

* STAS = Romanian Standard

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