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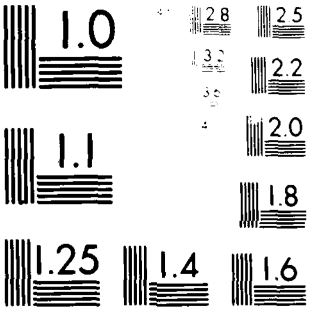

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A PROCEDURE FOR DETERMINING THE RESOURCE UTILIZATION POTENTIAL OF COAL ASH

James F. Karasek, Captain, USAF

LSSR 58-81

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A combination of the increased utilization of coal as an energy source and more stringent environmental regulations is creating problems for the disposal of the ash by-product from the combustion of coal. Utilization of the coal ash as an alternate resource has proven to be a partial solution to the problem. The U.S. Air Force coal conversion program will increase coal consumption and the production of coal ash; this has a potential to create a disposal problem for coal-burning bases. The purpose of this thesis was to develop a procedure to aid an engineer in determining the resource utilization potential of the coal ash at the base. The quality and quantity of the ash are the two main factors that affect the resource utilization potential of the ash. These two factors are a function of the nature of the feed coal, and the production, collection, handling, and storage systems utilized at the base. The procedure does not address the determination of the market potential of the ash, but rather its potential to be utilized as an alternate resource. The procedure provides a sequence of steps to follow in determining the resource utilization potential of a coal ash.

LSSR 58-81

A PROCEDURE FOR DETERMINING THE RESOURCE UTILIZATION POTENTIAL OF COAL ASH

A Thesis

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Engineering Management

By

James F. Karasek, BS
Captain, USAF

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This thesis, written by

Captain James F. Karasek

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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DATE: 30 September 1981

David R Lee
COMMITTEE CHAIRMAN

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CHAPTER I

INTRODUCTION

OVERVIEW

Civilian Sector

Coal ash is the by-product of the combustion process in coal-fired utility and industrial boilers and generally falls into two categories: fly ash and bottom ash. Fly ash is the powdery particulate collected from the flue gases, and bottom ash or boiler slag consists of the heavier particles that fall to the bottom of the furnace during the combustion process.

The production of coal ash in the United States climbed to a record high of 75.2 million tons in 1979. This is an increase of 50 million tons of ash per year over the 13 year period from 1966 when coal ash data collection was started. In 1966 25.2 million tons of coal ash were collected (32:3). The large increase in ash production during this period can be attributed to three factors:

1. The rapid degradation in the quality of coal being burned by the electric utilities in general has caused an increase in ash production. Prior to 1965 the ash content of the coal burned by utilities seldom exceeded 10 percent; however, it is now common to burn

coals having an ash content of 14 to 16 percent (7:13).

2. More coal is being used as a fuel source to satisfy present and forecasted energy needs. The amount of ash that is produced is a direct function of the amount of coal burned. After the 1973 Arab Oil Embargo, with the institution of higher oil prices and the growing shortages of oil and natural gas, the consumption of coal increased. In 1979, coal provided 20 percent of our energy. Of the 680 million tons of coal consumed, 77 percent was burned by electric utilities (37:63). To satisfy forecasted energy needs, utilities are building new coal-fired power plants and converting some existing power plants to coal. A survey by the National Coal Association (NCA) indicates there will be 259 new coal-fired power plants in operation by 1985. If new power plants are constructed as indicated by the NCA survey, ash production could approach 100 million tons per year by 1985 (16:71).

3. Utilities have been installing ash collection devices and using firing systems which allow higher ash collection efficiencies than those used in the past. With the advent of the Environmental Protection Agency, the Federal government took an active part in passing laws to control air, water, and land pollution. The Clean Air Act Ammendments of 1977 (PL95-95) prohibited significant air deterioration. As a result coal-fired power plants required electrostatic precipitators and bag houses to cut down the flow of particulates

from their stacks. This caused the power plants to collect larger quantities of coal ash. The disposal of the coal ash is also regulated by other environmental directives.

The disposal of coal ash has become an area of environmental concern. The two Federal laws which have the greatest impact on ash disposal are the Clean Water Act of 1977 and the Resource Conservation and Recovery Act of 1976 (RCRA). The stringent requirements promulgated under these acts and the Clean Air Act Amendments of 1977 for the collection and disposal of coal ash are costly for electric utilities to implement (13:p.3-5).

In an effort to hold down costs and lessen the impact of increased coal ash production, the Federal government, electric utilities, the coal industry, and private organizations have sponsored research to develop uses for coal ash. Some examples of ash utilization are: the production of cement and concrete products, subbase stabilization in road construction, a mineral fill in asphalt pavement, a landfill and embankment material, and an effective soil stabilizer (52).

Some benefits that have been realized from coal ash utilization are as follows:

Environmental. An increase in ash utilization will cause a corresponding decrease in the amount of ash that is disposed of as a waste material. Less land will be used for disposal sites and the potential for land and water pollution will be decreased. Also, an increase in the utilization of coal ash for aggregate in the construction industry has the potential to reduce the demand for the mining of natural aggregates (sand, gravel, etc.). Land areas containing these aggregates will not have to be disturbed by mining operations.

Energy and resource savings. The cement industry, one of our nation's major energy consumers, is rapidly becoming a major beneficiary of coal ash utilization. About 20 to 28 percent of the sales cost of cement corresponds to the cost of the energy consumed in the production process. Fly ash or granulated bottom ash can replace clinker in the production of blended cement. The replacement of 20 tons of clinker with fly ash in 100 tons of cement during the final grinding phase of the cement manufacturing process corresponds to an equivalent energy savings of 4 tons of coal plus 1,025 KWH of electricity. Additionally, the 20 percent replacement rate of fly ash for clinker results in a savings of 20 tons of the natural minerals that the fly ash replaced. The important point is that one ton of fly ash/cement requires only about 80 percent of the fuel consumption it takes to make one ton of standard cement (16:76).

The Coal Research Bureau at West Virginia University has developed a fly ash brick that can be manufactured with the expenditure of from 20 to 50 percent less energy than clay brick. Their report describes the areas in which energy savings can be realized when manufacturing fly ash brick. The report concludes

> There are several factors which contribute to the energy savings, but perhaps the largest factor is that flyash has undergone considerable heat work in the electric utility boiler and is a pre-fired material. Little additional heat work is required to form the ceramic bonds necessary to produce a superior quality brick [46:85].

The Environmental Protection Agency (EPA) feels that the potential for the use of fly ash is so great, in terms of materials and energy conservation, that it included fly ash in cement and concrete as one of the four major product guidelines under Section 6002 of the RCRA. This means that Federal agencies, state and local governments, grantees, and contractors who are using Federal funds for procurement must consider using either cement or concrete containing fly ash (22:51-52).

Just as electric utilities have switched to coal to help meet the energy needs and goals of our nation, the Air Force, in order to meet Department of Defense energy goals, is switching to coal and will experience an increase in coal ash production similar to that in the civilian sector.

Department of Defense

The President's Executive Order 12003, issued in July 1977, requires each Federal agency to develop a 10-year agency energy management plan and provide an annual progress report on goal achievement (48:1).

The Department of Defense (DOD), the largest single user of energy within the Federal government, has established firm energy policies and programs because the nation's overall defense posture depends on the availability of energy. DOD's energy objectives are to assure that energy shortages do not interfere with its capability to defend the nation, assist U.S. allies in overcoming their energy related defense problems, and prevent energy-related coercion of the United States or its allies. To accomplish its objectives, DOD required each Service to develop plans and policies, which, in accordance with national and DOD goals, would obtain an energy use reduction in existing buildings of 20 percent and derive at least 10 percent of installation energy use from sources other than petroleum and natural gas by 1985 (48:1-2). These goals are listed in the Defense Energy Program Policy Memorandum (DEPPM) 78-2.

Air Force

To ensure that it has enough energy at a reasonable cost, and to comply with national and DOD objectives to reduce or eliminate dependence on energy from rapidly depleting and increasingly costly resources, the Air Force established energy program guidelines. One of these guidelines is to demonstrate the use of alternate fuels for aircraft and base operations, and eventually establish a multifuel capability for all Air Force systems (48:2).

The Air Force's alternate fuel conversion program was established under this guideline. One of the objectives of this program is the use of alternative or nonconventional energy forms, coal, refuse derived fuel, wood, and biomass to provide at least 10 percent of the energy used in Air Force installations (3:27). This research effort is concerned with the part of the alternate fuels program that deals with the conversion of oil- or gas-fired plants to coal, and the construction of new central coal-fired plants for Air Force installations.

PROBLEM ANALYSIS

In support of its goal to obtain 10 percent of its installation energy from alternative or nonconventional energy forms, the Air Force has focused on converting its heat plants fueled by oil or natural gas to coal (3:36). The first project in the coal conversion program is at F.E. Warren AFB; this central coal-fired heat plant is scheduled to be completed in 1981. A second project is planned for Fairchild AFB. An additional 12 coal-conversion projects are proposed through FY83.

Another nine bases are being considered for the installation of coal-fired central heat plants. The conversions are in support of the Air Force long term energy goal to obtain at least 25 percent of installation energy from alternate energy forms by the year 2000 (1:p.3-1). The Air Force Facility Energy Plan FY 76-85 lists five more bases that are to be converted to coal in future years (1:p.3-5).

At present the Air Force has 11 bases utilizing coal-fired heat plants. The coal conversion program has the potential to more than triple this number to 38 bases utilizing coal-fired central heat plants. See Appendix B for a list of present coal-fired installations and those being considered for coal conversion.

As the Air Force converts more bases to burning coal, coal ash production in the Air Force will increase as it has for industry in the civilian sector. Utilization of the coal ash from the bases being converted to coal is given some consideration by engineers during the 20 percent design phase (9).

PROBLEM STATEMENT

Plans to increase the number of bases burning coal will increase coal ash production in the Air Force. The utilization of coal ash as a recyclable resource has been proven through laboratory and field testing. At present there is no guidance or standard procedure available in the Air Force to help a base engineer determine the resource utilization potential of the coal ash produced at the base.

RESEARCH OBJECTIVES

The purpose of this research is to provide a procedure that will help a base engineer determine the resource utilization potential of the coal ash produced at the base. This will be accomplished through the following objectives and their respective research questions.

Objective I

Develop a model that will enable identification of the factors which affect the utilization potential of coal ash.

Research Questions

1. How is utilization potential defined?

2. What factors affect utilization potential and how are they defined?

3. What interaction is there, if any, among the factors?

Objective II

Develop a procedure to analyze the portions of the model that will aid a base engineer in determining the utilization potential of the coal ash.

Research Questions

1. How are the factors in the model measured?

2. What is the systematic procedure for using the model?

Definition of Terms and Concepts

Technical terms, acronyms, and concepts used throughout this paper are found in Appendix A. Acronyms are defined in the initial appearance and are used interchangably with their entire definition throughout the text as appropriate.

JUSTIFICATION FOR RESEARCH

At present Air Force base engineers do not have any guidance or standard procedure to analyze the resource potential of the coal ash by-products produced at Air Force coal-fired heat plants. In an attempt to comply with national and DOD energy goals, the Air Force is planning to convert many of its heat plants to coal as a fuel source. In an address before the Congress, Major General Gilbert, Director of Engineering & Services, Headquarters USAF, stated

> ...The second keystone of our energy program is to reduce dependence on fuel supplies that could be curtailed or cut off by substituting more abundant and available alternate fuels. The primary means of accomplishing this goal is to convert our large natural gas and fuel oil plants to coal...[2:p. 1-A-4].

The Air Force utilities branch for coal conversion (USAF/LEEEU) considers the resource utilization potential of the coal ash from Air Force coal-fired heat plants to be an important issue that deserves a research effort (9).

SCOPE OF THE RESEARCH

This research is concerned with the development of a procedure to determine the resource utilization potential of the coal ash from Air Force bases. The key word in the previous sentence is potential. The coal ash at a specific Air Force base may have the potential to be used as a resource for cement manufacture. However, if there are no nearby cement manufacturing plants, the value of the coal ash as a resource for cement manufacturing is diminished.

This research is limited to determining the resource utilization potential of the coal ash and is not concerned with the economic factors that affect the marketing and sale of coal ash.

RESEARCH METHODOLOGY

The development of the procedure was accomplished in two phases. The first phase entailed the development of a model that would provide for identification of the factors affecting the utilization potential of the coal ash. In the second phase, a procedure was developed for analyzing or measuring the elements of the model developed in phase one.

Model Development

Model development began with a review of the literature pertaining to coal ash and the utilization of coal ash as a resource. The review started with a literature search through the Defense Technical Information Center and a review of the Reader's Guide to Periodical Literature. The Encyclopedia of Associations published by Gale Research Company was reviewed to identify any associations that study or promote the utilization of coal ash. The 1981 Thomas Register of Products and Services was also reviewed to identify any companies involved with coal ash.

Actual model development started by defining the term resource utilization potential as it applies to coal ash. Next the factors that affect the utilization potential of coal ash were identified and defined. Then the factors were examined for any interaction.

In effect, the model was developed by starting with the end product of the coal combustion process, coal ash, and working backward from the utilization of coal ash, to the factors affecting utilization potential, to the raw mineral coal, which is the beginning point in the process.

Development of Analytical Procedure

Development of the analytical procedure is based upon the model. Whereas, the model was developed by defining the resource utilization potential of coal ash and working backward to identify and define the factors that affect the utilization potential of coal ash, the development of the procedure starts with the factors identified in the model and works forward to the resource utilization potential of coal ash.

Actual development of the procedure started by taking each of the factors identified and defined in the model and determining how these factors may be measured. The literature review provided accepted standards for measurement of the factors.

PLAN OF THE REPORT

The research is presented in a format that follows the basic outline presented by the research objectives. Chapter II includes a general discussion about the basics of coal ash. The production, collection, handling, and storage of coal ash are discussed. Also, current resource utilization applications and examples of these applications are reviewed. In Chapter III the model is presented and its development explained. Chapter IV contains the procedure that was developed to support utilization of the model presented in Chapter III. Chapter V includes a test case to demonstrate how the procedure is used. Chapter VI contains a summary of the research effort and recommendations for future research.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

Coal ash is the by-product of the combustion process in coal-fired utility and industrial boilers. These boilers generate coal ash in three forms: fly ash, bottom ash, and boiler slag. Fly ash is the very fine, non-combustible residue which is carried off in the stack gases from the boiler units and collected by the flue gas cleaning equipment. It is composed of the non-combustible mineral matter present in coal and carbon due mainly to incomplete combustion. Bottom ash and boiler slag are the heavier ash particles which are collected at the bottom of the boiler.

The chemical and physical properties of a particular coal ash are a function of many factors, including (13:p.2-1):

- type of coal and geographic source
- degree of coal preparation, cleaning, and pulverization
- design, type, and operation of the boiler unit
- collection, handling, and storage/disposal methods

Due to these factors, the ash will display a high degree of variability in its properties. Not only will the properties of an ash vary from power plant to power plant, but they will also vary from boiler to boiler at a particular plant and within an individual boiler at times.

In this chapter, the effect that various combustion and collection techniques have on the properties of the ash will be shown; typical chemical and physical properties of fly ash, bottom ash, and boiler slag will be presented; and, examples of ash utilization will be reviewed.

COMBUSTION AND COLLECTION EQUIPMENT

The total quantity of ash produced is a function of the ash content of the coal burned. The quantity and properties of each form of ash produced also depend upon the type and operation of the boiler unit, collection and handling equipment, and storage/disposal method.

Production of Ash

The formation of coal ash takes place in the furnaces of the boilers which produce steam for heating or for generating electric power. There are three types of furnaces which are in use today (13:p.2-10):

- pulverized coal-fired furnaces
- cyclone furnaces
- stoker-fired furnaces

Pulverized coal-fired units are widely used in the electric power industry for installations where greater than 50,000 pounds of steam per hour must be produced. They are especially prevalent in installations requiring a production of over 250,000 pounds of steam per hour. The coal is dried and pulverized so that 80 percent of the particles are smaller than 0.074 mm. The pulverized coal is aerated and transferred to the burners, where combustion takes place. Ash can be removed from the bottom of the furnace in a molten state and quenched in water (boiler slag) or in a solid granular form (bottom ash). If the ash leaves the furnace in a molten (liquid) state, the boiler is referred to as a wet-bottom boiler, and if the ash is removed in a solid granular form, the boiler is called a dry-bottom boiler. Approximately 80 percent of the ash produced in pulverized coal-fired units with dry-bottom removal systems exits from the furnace in the flue gas stream as fly ash, leaving 20 percent of the ash as bottom ash. Typically, 65 percent of this fly ash is finer than 0.010 mm. For units with a wet-bottom removal system, the percentage of fly ash produced drops to about 50 percent and the quantity of ash forming boiler slag increases accordingly.

Cyclone furnaces use crushed coal with a diameter of less than 12.7 mm as fuel and are comparable in steam generation capacity to pulverized coal-fired furnaces. The coal is burned by continuous swirling in a high-heat-intensity zone. Between 80-85 percent of the ash melts and is tapped from the furnace as boiler slag, leaving 15 to 20 percent of the ash to exit in the gas stream as fly ash. Approximately 90 percent of the fly ash which leaves the furnace in the stack gases is finer than 0.010 mm.

Stoker-fired furnaces are used to fire boilers which must generate from 10,000 to 25,000 pounds of steam per hour. The stoker-fired units have a system which mechanically feeds the coal into the furnace, provides the proper amount of air for combustion, and then mechanically removes the unburned refuse. There are three types of stokers in use (15:p.2-2):

- underfeed stokers
- traveling or chain-grate stokers
- spreader stokers

The underfeed stoker is suitable for use with semibituminous (coking) coals. The traveling or chain-grate stoker is used primarily for those furnaces which burn anthracite or Middle Western U.S. bituminous coals. Spreader stokers can be used with a variety of coals. The fly ash which is produced by stoker-fired units is coarser than the fly ash produced by either pulverized coal-fired units or cyclone furnaces. Underfeed stokers and traveling grate stokers will produce 10 to 20 percent fly ash, with the remainder of the ash being collected as bottom ash. Of the fly ash collected only 5 percent will be less than 0.010 mm. Generally, 15 to 55 percent of the total ash produced by spreader stokers is fly ash and 10-45 percent of this fly ash is less than 0.010 mm.

Collection of Ash

Fly ash. There are various methods for collecting fly ash, each with its own characteristics and efficiencies. In general, currently available particulate control equipment can be classified as follows (13:p.2-11):

- mechanical collectors
- fabric filters (bag house)
- wet scrubbers
- electrostatic precipitators

There are various advantages to the use and/or applicability of a particular type or series of particulate control devices. In general, the decision is a matter of balancing the required collection efficiency versus the overall cost of the system (13:p.2-13). Table 2-1 indicates various operating parameters for the most common particulate control devices.

One specific effect which the type of particulate control equipment has on the fly ash is the grain size distribution of the collected ash. The fly ash from an electrostatic precipitator or venturi scrubber will have a similar gradation whereas fly ashes from a cyclone will have a coarser gradation due to the respective collector efficiencies.

Bottom ash/boiler slag. In dry bottom boilers, the bottom of the fire box has an open grate construction. The heavy ash particles (bottom ash) fall through this grate into a water filled hopper. Wet bottom boilers and cyclone furnaces have a solid base at the bottom

TABLE 2-1

SEVERAL OPERATING CHARACTERISTICS OF PARTICULATE COLLECTORS [51; 13:p.2-12]

General Class	Specific Type	Typical Capacity	Pressure Loss (in. water)[a]	Power Reqd. ($W/ft^3/min$)[b]	Overall Efficiency (%)	Fractional Efficiency in Percent For Various Size Ranges in Microns				
						0-5	5-10	10-20	20-44	>44
Mechanical collectors	Settling chamber	15-25 ft^3/min per ft^3 of casing volume	0.2-0.5 (0.5-1.3)	0.03-0.10 (1-4)	-	-	-	-	-	-
	Baffle	1000-3500 ft^3/min per ft^2 of inlet area	0.5 (1.3)		60	7.5	22	41	80	90
	Conventional cyclone				65	12	35	57	82	91
	High-efficiency cyclones	2500-3500 ft^3/min per ft^2 of inlet area	3-5 (7.5-12.5)	0.5-1.0 (15-35)	85	40	79	92	95	97
Fabric filters	Automatic	1-6 ft^3/min per ft^2 of fabric area	4-6 (10-15)	1.0-1.3 (35-45)	99+	99.5	100	100	100	100
Wet scrubbers	Impingement baffle	400-600 ft^3/min per ft^2 of baffle area	2-5 (5-13)	0.2-1.0 (7-35)	-	-	-	-	-	-
	Packed tower	500-700 ft^3/min per ft^2 of bed cross-sectional area	6-8 (15-20)		94	90	96	98	100	100
	Venturi	6000-30,000 ft^3/min per ft^2 of throat area	10-50 (25-125)	4-12 (140-425)	99+	99	99.5	100	100	100
Electrostatic precipitators	Dry, single-field	2-8 ft^3/min per ft^2 of electrode collection area	0.2-0.5 (0.5-1.3)	0.4-1.0 (15-35)	97	72	95	97	99+	100
	Wet (charged-drop scrubber)	5-15 ft^3/min per ft^2 of electrode collection area	0.5-0.7 (1.3-1.8)	0.3-0.5 (10-15)	-	-	-	-	-	-

[a] Values in parentheses under "pressure loss" are in mbars.

[b] Values in parentheses under "power required" are in $W/m^3/min$.

of the firebox. In the base is an orifice which is opened to allow the molten ash (boiler slag) to flow into the water filled hopper. The ash solidifies upon quenching and then is crushed, if necessary, to break up any large pieces of ash and aid in the handling process. The bottom ash consists of angular particles with a porous surface texture and the boiler slag angular particles with a glassy appearance (13: p.2-14).

Handling of Ash

Fly ash.

After the fly ash has been removed from the flue gas stream, it must be transported to a temporary storage silo or the ash slucing area. If the fly ash is collected by one of the dry methods, there are three types of dry handling systems which can be used to transport the fly ash from the points of collection to the silo or sluice lines (15:p.2-6):

- vacuum systems
- pressure systems
- combination vacuum-pressure systems

Vacuum systems have a limit on the effective distance to which they can transport the fly ash. The maximum distance which material can be conveyed by a vacuum system is dependent upon the configuration of the system and the altitude above sea level. Pressure systems are generally used where the length of conveyance is too great for a vacuum system or where the altitude limits the vacuum which can be created. Combination systems are usually economical where the length of the conveying system exceeds the capability of a vacuum system to attain a satisfactory conveying rate.

If the fly ash is removed from the flue gas stream by a wet collector, it will be sluiced to a pond for dewatering or disposal. The use of water will affect some of its chemical properties. In general, the use of water will tend to dissolve some of the fly ash particles and the chemical deposits on the surface of other fly ash particles.

Bottom ash/boiler slag. The bottom ash, boiler slag which has been collected in the hopper is sluiced to either a settling pond or a dewatering bin. The sedimentation pond can be either a temporary holding facility or a final disposal site. If the ash is to be sold or disposed of at a dry landfill site, it is removed from the pond and stacked to allow the water to drain prior to shipment. The ash may also be sluiced to a dewatering bin if it has a commercial value. This type of structure allows for a much more rapid dewatering of the ash and facilitates the loading of the ash for transport.

Storage of Ash

The storage techniques for ash can be divided into two broad categories of dry and wet methods. In 1978, 51 percent of the ash was stored by the wet method and 49 percent by the dry method (13:p.3-2).

In the dry method of storage, the fly ash is conveyed by either vacuum or pressure system to the storage silo. The storage silos are made of carbon steel or hollow concrete stave construction. Flat bottom silos are equipped with aeration stones or slides to fluidize the ash and induce flow when discharging of the ash takes place (15:p.2-9).

The bottom ash/boiler slag is sluiced into a dewatering bin; ashes are settled and the water is removed through decanting and dewatering elements, so that relatively dry ash can be delivered to trucks or railroad cars. Dewatering bins are constructed of carbon steel plate of thicknesses that depend upon the bin diameter and loading conditions (4:13).

Storage silos and dewatering bins are used only for short term storage. If there is not an immediate need for the ash, it must be transferred to a stockpile location. The ash can be transported to the stockpile area by either truck or rail. Except with pneumatic tankers, it is necessary to condition the fly ash with a small amount of water prior to transport to prevent it from blowing off the transport vehicle and creating an environmental problem. Whether or not the bottom ash/boiler slag needs conditioning, will depend on the degree to which the ash is dewatered.

The wet method of storage involves the addition of large quantities of water to the dry fly ash to create a slurry. The mixing of the water with the dry fly ash occurs at the vacuum producer in a vacuum handling system. The slurry is then discharged through an air separator tank into the bottom ash discharge pipe. Fly ash is generally mixed with bottom ash for transport to the storage lagoon because the scouring action of the larger bottom ash particles will remove any scale build-up caused by the fly ash. The ash mixture then flows by gravity or is pumped to the ash storage lagoon. In the lagoon, the bottom ash and fly ash settle out and the excess water is carried away.

The method used for handling and storage may influence the potential of ash utilization schemes. There is a marked trend toward dry collection and storage systems and the separation of bottom ash and fly ash (16:71). Reasons for these changes included increased ash marketability and the reduced disposal volume for that portion of the ash utilized. Also influencing this change are increasingly stringent effluent regulations for ash transport water and increased environmental concerns with operating present wet ash systems.

PROPERTIES OF COAL ASH

In this section typical chemical and physical properties of ash will be presented.

Chemical Properties

The chemical composition of coal ash varies widely in concentrations of both major and minor constituents. Table 2-2 summarizes some data on variations in coal ash composition by coal rank.

The principal factor affecting the variation in the composition is the variability in the minerology of the coal. However, differences in composition can exist between fly ash and bottom ash (or boiler slag) generated from the same coal due to differences in the degree of pulverization of the coal prior to firing, the type of boiler in which the coal is fired, and the boiler operating parameters and combustion efficiency. Regardless of the type of ash, either fly ash or bottom ash, usually more than 80 percent of the total weight of the ash is composed of silica, alumina, iron oxide and lime (43:416). Carbon can also be present in various amounts. Older boilers tend to produce higher carbon fly ash than the new, more efficient units.

As much as 20 percent of the fly ash can be water-soluble, so the potential exists for the release of contaminants through leaching (43:416). The principle ions contained in the leachate are calcium and sulfate, with smaller quantities of magnesium, sodium, potassium, and silicate ions present. Free lime (CaO) accounts for part of the soluble calcium. The soluble sulfate is approximately half the total sulfate (SO_4) present in the fly ash. Leachates resulting from ash are usually alkaline with a pH value ranging from 6.2 to

TABLE 2-2

VARIATIONS IN COAL ASH COMPOSITION WITH RANK [41; 13:p.2-16]

	Rank			
	Anthracite	Bituminous	Subbituminous	Lignite
% SiO_2	.48 - 68	7 - 68	17 - 58	6 - 40
% Al_2O_3	25 - 44	4 - 39	4 - 35	4 - 26
% Fe_2O_3	2 - 10	2 - 44	3 - 19	1 - 34
% TiO_2	1.0 - 2	0.5 - 4	0.6 - 2	0.0 - 0.8
% CaO	0.2 - 4	0.7 - 36	2.2 - 52	12.4 - 52
% MgO	0.2 - 1	0.1 - 4	0.5 - 8	2.8 - 14
% Na_2O	-	0.2 - 3	-	0.2 - 28
% K_2O	-	0.2 - 4	-	0.1 - 1.3
% SO_3	0.1 - 1	0.1 - 32	3.0 - 16	8.3 - 32
% Ash	4 - 19	3 - 32	3 - 16	4 - 19

11.5 (13:p.2-21). A high available alkalinity is particularly characteristic of ash from low sulfur Western U.S. subbituminous and lignite coals.

An important property of fly ash is its pozzolanic potential. Fly ash is an artificial pozzolan, i.e., a siliceous or alumino-siliceous material which is not cementitious in itself, but which in finely divided form and in the presence of moisture reacts with alkali and alkaline earth products to produce cementitious products (13: p.2-19). A large percentage of the components in fly ash are in the form of a glass called mullite ($3Al_20_3 \cdot 2SiO_2$). When lime and water are present with the mullite, the glass experiences an alkali attack which results in the creation of calcium silicate hydrates and calcium alumino-silicate hydrates, similar to the primary cementitious agents formed by the hydration of Portland cement. Some fly ashes contain enough free lime to react with other components of the fly ash upon the addition of water to produce a cementitious compound. When this reaction occurs the fly ash is referred to as self-hardening. If a fly ash has this self-hardening capability, then some of its physical properties, i.e., shear strength, compressibility, permeability, and frost susceptibility will be affected. The shear strength will increase with time and the other three parameters will decrease (13:p.2-19).

For any particular type of coal, the chemical composition of the bottom ash or boiler slag derived from this coal will be similar to, but may have a lower carbon content than, the fly ash from which it is derived. Table 2-3 shows the chemical composition of five bottom ashes and boiler slags from bituminous coal. The pozzolanic activity of bottom ash is less than that of fly ash. Boiler slag is generally less pozzolanic than either bottom ash or fly ash.

Physical Properties

The physical properties of ash which are of concern when it is to be used as an engineering construction material are (13:p.2-27):

- grain-size distribution
- moisture content
- shear strength
- compressibility
- permeability
- capillarity
- frost susceptibility

The explanation of each property and why it is important has been condensed from the Coal Ash Disposal Manual, available from the Electric Power Research Institute (EPRI) as report FP-1257.

Grain size distribution is important because many engineering parameters are related to the variation of particle sizes of the material. This distribution is generally presented in graphical form in a grain size distribution curve. The characteristics of the grain-size distribution for a given material can be defined from the grain-size curve. For example, a material having a steep curve has a

TABLE 2-3

CHEMICAL ANALYSIS OF FIVE BOTTOM ASHES OR BOILER SLAGS

[45; 13:p.2-18]

	Percentage of Total Composition				
Component	Boiler Slag 1	Boiler Slag 2	Boiler Slag 3	Bottom Ash 1	Bottom Ash 2
Silica	48.9	47.1	53.6	53.6	45.9
Alumina	21.9	28.3	22.7	28.3	25.1
Iron Oxide	14.3	10.7	10.3	5.8	14.3
Calcium Oxide	1.4	0.4	1.4	0.4	1.4
Magnesium Oxide	5.2	5.2	5.2	4.2	5.2
Sodium Oxide	0.7	0.8	1.2	1.0	0.7
Potassium Oxide	0.1	0.4	0.1	0.3	0.3
Sulfur Trioxide	-	-	-	-	-
Undetermined	7.5	7.1	5.5	6.4	7.1

very small range of particle sizes and is said to be uniformly graded. A material having a flat curve is indicative of a well dispersed assortment of material particle sizes and the material is said to be well-graded. A well-graded material can be readily compacted to a dense condition, and will develop greater shear strength and lower permeability than uniformly-graded material.

Figure 2-1 indicates that bituminous fly ash is usually uniformly-graded material with particles primarily in the silt range (particle diameters between 0.005 mm and 0.074 mm). The particle size of fly ash ranges from 0.001 mm to 0.100 mm in diameter for the glassy spheres, with an average of 0.007 mm, and from 0.010 mm to 0.300 mm in diameter for the more angular carbon particles. The grain-size distribution of fly ash can be improved by blending it with bottom ash or boiler slag.

Figure 2-2 indicates the range of grain-size distributions for bottom ash and boiler slag. These two materials will have particles ranging in size from fine sand to fine gravel. Generally, the boiler slag will be more uniform in size than the bottom ash.

Moisture content. The moisture content of an ash is a measure of the amount of water present in the voids in the ash. It is of interest because it determines both the weight and behavior of the ash. The weight of a quantity of ash is the sum of the weight of the solid ash

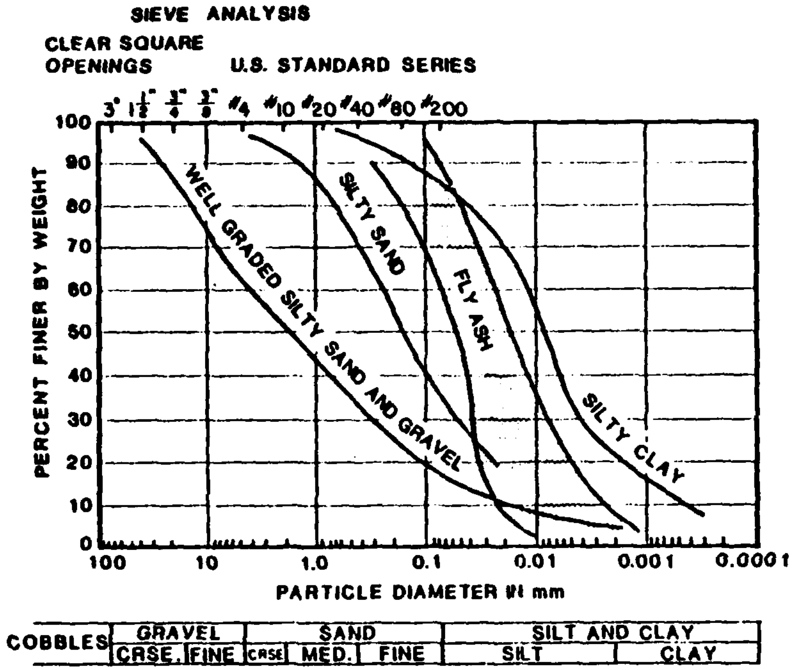

Figure 2-1: Grain Size Distributions for Bituminous Fly Ash [18; 13:p.2-28]

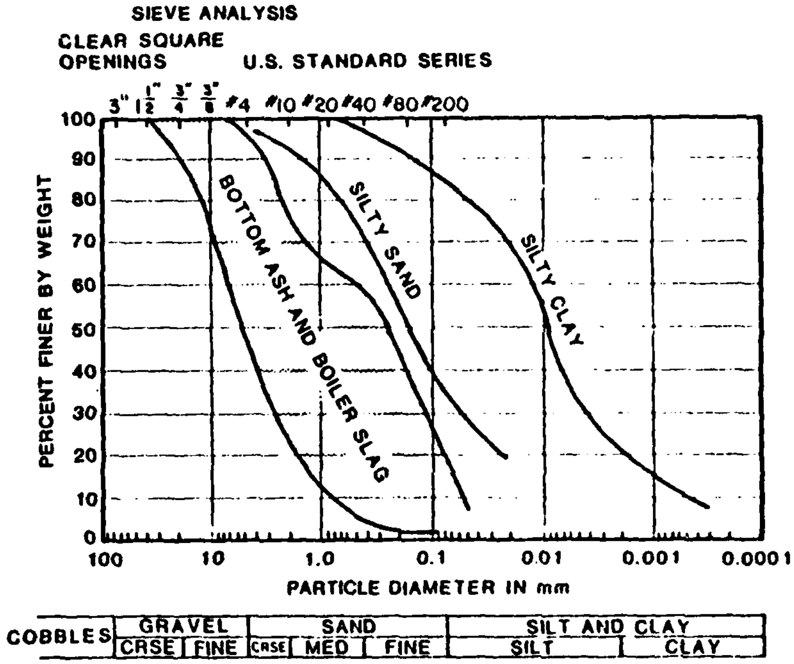

Figure 2-2: Grain Size Distributions for *Bituminous* Bottom Ash and Boiler Slag [45; 13:p.2-28]

particles as well as the weight of any water in the voids. Since the weight of the water can be a significant fraction of the total, and since the cost of handling and transporting ash can be weight dependent, the quantity of water included in the ash is an important consideration. The influence of moisture content on fly ash behavior can be equally important. A particular fly ash may be a dusty powder or soupy mud depending solely upon moisture content. Thus, moisture content will affect engineering properties such as compaction behavior and shear strength.

Moisture content is expressed as a percentage of the ash's dry weight and is determined by dividing the weight of the water in the voids by the weight of the ash when dry and then multiplying this quotient by 100. Due to this method of determination, it is possible to have moisture contents in excess of 100 percent. Typical values of natural moisture content are 2 to 5 percent for silo-stored ash and 50 to 110 percent for ash stored in ash ponds.

Density. The density of the ash is important because it influences the permeability, stiffness, and strength of the ash. As the density of a granular material increases, so does its strength.

A portion of the total volume of the ash is occupied by pore spaces, or voids, which can contain either water or air. If the pore spaces contain only air, then the density of the ash is referred to as the dry density. If all or part of the voids are filled with water, then the ash will have a dry density with a corresponding moisture content. If all the voids are filled with water, the ash is in a saturated state.

Shear strength. The shear strength of the ash is important because it determines the steepness of fill slopes which can safely be constructed and the magnitude of the loads which can be safely supported by the ash. The shear strength of a soil is related to two engineering properties: cohesion and the angle of internal friction. Cohesion is a measure of the shear strength developed by the attraction of individual particles for one another. The angle of internal friction is a measure of the frictional resistance between particles. The magnitude of the shear strength developed through interparticle friction is equal to the product of the normal force applied to the material and the tangent of the angle of internal friction. Table 2-4 shows typical values for the cohesion and internal angle of friction for fly ash and bottom ash along with the values for various soil types.

Fly ashes which do not have self-hardening properties possess no cohesion; however, they exhibit some apparent cohesion due to capillary forces produced by pore water. This apparent cohesion can be destroyed by complete drying or saturation. Fly ashes which will self-harden develop a strength which is often referred to as cohesion;

TABLE 2-4

TYPICAL SHEAR STRENGTH CHARACTERISTICS FOR VARIOUS TYPES OF COMPACTED SOILS

(13:p.2-33)

Soil Type	Cohesion (Saturated) psf	Cohesion (Saturated) kg/m^2	Angle of Internal Friction
Well graded clean gravel	0	0	>38°
Poorly graded clean gravel	0	0	>37°
Silty gravel	--	--	>34°
Clayey gravel	--	--	>31°
Bottom ash, boiler slag	0	0	>38°
Well graded clean sand	0	0	38°
Poorly graded clean sand	0	0	37°
Silty sand	420	2050	34°
Sand, silt, clay mixture	300	1460	33°
Clayey sand	230	1100	31°
Fly ash (non-self-hardening)	0	0	25° - 40°
Inorganic silts	190	930	32°
Low plasticity inorganic clays	270	1320	28°
High plasticity inorganic clays	230	1100	19°

however, this strength more closely resembles the chemical bonding strength of cement than the cohesive strength of a soil.

The angle of internal friction of bituminous fly ash varies with the degree of compaction and is generally in the range of 25° to 40°. There have not been many studies published on the strength of subbituminous and lignite ashes so that typical ranges of strength parameters, such as cohesion and angle of internal friction, for these ashes are not available.

As with fly ash, the shear strength of bottom ash and boiler slag will vary with the degree of compaction. The angle of internal friction for bottom ash and boiler slag in a loose condition can vary from 38° to 42.5°.

Compressibility. The compressibility of fly ash is important because it determines the rate and magnitude of settlement of any structures which may eventually be founded on a fill composed of fly ash. In contrast to its shear strength behavior where it behaves as a cohesionless material, fly ash behaves very much like a cohesive soil in terms of consolidation and settlement. That is, upon application of vertical pressure, the stress is initially shared by the soil structure and pore water. The excess pore water pressure gradually decreases as the water is squeezed out of the pores, and as the pore water pressure decreases, the load is transferred to the fly ash structure, producing a volume change. Laboratory consolidation tests have indicated that compaction can significantly reduce the compressibility of fly ash. Table 2-5 shows some typical values for the compressibility of fly ash and bottom ash along with various soil types.

Permeability. A material is considered permeable if it has interconnected pores, cracks, or other passageways through which water or gas can flow. It is important as a factor in determining at what rate a leachate may travel through the ash fill. Typical values of the coefficient of permeability for fly ash and bottom ash along with various soil types are shown in Table 2-6.

The engineer's coefficient of permeability applies to the flow of water and was developed as a convenient means of estimating the quantity of water which will seep through a mass of earth in a given time period. The permeability of a soil mass is a function of the viscosity of the water, the grain-size distribution, the degree of compaction of the soil mass, and the number of discontinuities present in the soil mass. The permeability of bituminous fly ash compacted to its maximum dry density has varied from 0.104 to 104 ft/yr in laboratory tests. The coefficient of permeability for bituminous bottom ash/boiler slag has been shown to vary from 31,200 to 93,600 ft/yr.

Table 2-5

TYPICAL VALUES OF COMPRESSIBILITY FOR VARIOUS TYPES OF COMPACTED SOILS (13:p.2-35)

Soil Type	Compressibility [Percent of Original Height @ 50 psi (345 k Pa)]
Well graded clean gravel	0.6
Poorly graded clean gravel	0.9
Silty gravel	1.1
Clayey gravel	1.6
Bottom ash, boiler slag	1.4
Well graded clean sand	1.2
Poorly graded clean sand	1.4
Silty sands	1.6
Sand, silt, clay mixture	1.4
Clayey sand	2.2
Fly ash	1.8
Inorganic silt	1.7
Low plasticity inorganic clay	2.5
High plasticity inorganic clay	3.9

Table 2-6

TYPICAL COEFFICIENTS OF PERMEABILITY FOR VARIOUS TYPES OF COMPACTED SOILS (13:p.2-36)

Soil Type	Coefficient of Permeability (ft/yr)	Coefficient of Permeability (cm/sec)
Well graded clean gravel	52,000	5×10^{-2}
Poorly graded clean gravel	104,000	10^{-1}
Silty gravel	>1.04	$>10^{-6}$
Clayey gravel	>0.104	$>10^{-7}$
Bottom ash, boiler slag	52,000	5×10^{-2}
Well graded clean sand	>1040	$>10^{-3}$
Poorly graded clean sand	>1040	$>10^{-3}$
Silty sand	52	5×10^{-5}
Sand, silt, clay mixture	2.08	2×10^{-6}
Clayey sand	0.52	5×10^{-7}
Fly ash	0.104 - 104	$10^{-7} - 10^{-4}$
Inorganic silt	10.4	10^{-5}
Inorganic clay	0.104	10^{-7}

Capillary rise. Capillary rise is the physical phenomenom in which a liquid, such as water, is drawn into a tube of very small diameter due to the surface tension forces. Because of its grain-size distribution, this same activity will occur in compacted, fine fly ash. Capillary rise is of concern when fly ash is used in a fill application because the fly ash can become saturated by ground water which is drawn up into the ash by capillary action. If this occurs, the ash will lose some of its strength and the landfill could become unstable.

Frost susceptibility. Materials with a grain-size distribution such as fly ash are generally susceptible to frost heave when exposed to freezing temperatures and a source of water. Frost heave in soils is caused by the freezing of the water in the soil pores. Frost susceptibility is of concern because the stability of a fly ash fill could be adversely affected by frost heave. The susceptibility of a soil to frost heave is a function of the tensile strength of the soil and its permeability. As the tensile strength increases and permeability decreases, the ability of the material to resist frost heave increases. For this reason, self-hardening fly ashes are less susceptible to the problems of frost heaving than are the non-self-hardening ashes. The only means of accurately determining if a particular fly ash will be frost susceptible is through laboratory tests under freezing conditions. Bottom ash and boiler slag have a low susceptibility to frost heave when well drained.

EXAMPLES OF ASH UTILIZATION

In this section the utilization of coal ash as a resource will be reviewed. Table 2-7 contains the results of a survey made by the National Ash Association on ash collection and utilization in 1979. Examination of the uses listed under commercial utilization shows that the primary area of utilization is in the construction industry. Miscellaneous applications include that of a filter aid in treating sewage wastes, a compaction and cover media in sanitary landfills, an aid in the revegetation of abandoned strip-mined lands, to control underground fires in coal refuse piles, and as a substitute for lime in conventional SO_2 lime-based removal systems installed to control utility stack pollution.

Information provided in this section illustrates the present use of coal ashes and provides the reader with some insight as to the potential for increasing the utilization of coal ash.

Cement, Concrete and Concrete Products

Fly ash has been extensively investigated and widely used in the United States and other countries as an ingredient in Portland-cement concrete mixtures. The fly ash may be used as an interblended ingredient to replace up to 20 percent of the clinker used to

TABLE 2-7

ASH COLLECTION AND UTILIZATION SURVEY
[32:3]

Ash Collection & Utilization 1979

(Million Tons)

	Fly Ash Tons x 10^6	Bottom Ash Tons x 10^6	Boiler Slag (if separated from Bottom Ash) Tons x 10^6
1. TOTAL ASH COLLECTED	57.5	12.5	5.2
2. ASH UTILIZED	10.0	3.3	2.4
A. COMMERCIAL UTILIZATION			
a. Mixed with raw material before forming cement clinker	62		
b. Mixed with cement clinker or mixed with cement (Type 1-P cement)	.21		
c. Partial replacement of cement in concrete and blocks	1.9		
d. Lightweight aggregate	64		
e. Fill material for roads, construction sites, land reclamation, ecology dikes, etc.	1.0		
f. Stabilizer for road bases, parking areas, etc.	1.2		
g. Filler in asphalt mix	.6		
h. Miscellaneous	.4		
ASH DISPOSED OF AT A PROFIT	6.6		
B. ASH REMOVED FROM PLANT SITES AT NO COST TO UTILITY	1.4		
C. ASH UTILIZED FROM DISPOSAL SITES AFTER DISPOSAL COSTS	2.0		
TOTAL ASH UTILIZED	10.0		

Comparative Results

	1966*	1975	1976	1977	1978	1979
Ash Collected						
Fly Ash	17.1	42.3	42.8	48.5	48.3	57.5
Bottom Ash	8.1	13.1	14.3	14.1	14.7	12.5
Boiler Slag		4.6	4.8	5.2	5.1	5.2
TOTAL ASH COLLECTED—TONS x 10^6	25.2	60.0	61.9	67.8	68.1	75.2
Ash Utilized						
Fly Ash	1.4	4.5	5.7	6.3	8.4	10.0
Bottom Ash	1.7	3.5	4.5	4.6	5.0	3.3
Boiler Slag		1.8	2.2	3.1	3.0	2.4
TOTAL ASH UTILIZED—TONS x 10^6	3.1	9.8	12.4	14.0	16.4	15.7
Percent of Ash Utilized						
% Fly Ash	7.9	10.6	13.3	13.0	17.4	17.4
% Bottom Ash	21.0	26.7	31.5	32.6	34.0	26.4
% Boiler Slag		40.0	45.8	60.0	58.8	46.0
PERCENT OF TOTAL ASH UTILIZED	12.1	16.4	20.0	20.7	24.1	21.0

*First year that data was taken

**1967-1974 data omitted from tabulation because of space limitation.

Compiled by the National Ash Association and Edison Electric Institute.

12 1 80)

produce Portland cement. The blended cement is then called Portland-pozzolan cement. The cement is mixed with water, sand, and gravel to produce concrete. Also, the fly ash may be employed as an admixture added as a separate ingredient to the concrete mixture. In this method the fly ash acts as a replacement for the sand and gravel in the concrete mixture. Granulated bottom ash may also be used as an admixture to concrete. In most cases fly ash/bottom ash is used as an admixture to the concrete rather than a replacement for the cement clinker (27:1).

Some documented beneficial effects of using fly ash in concrete are (39:548-549):

- concrete is easier to work
- compressive strengths are typically higher
- shrinkage and cracking are reduced
- concrete is more impermeable to water
- resists deteriorating effect of sulfate soils and sea water
- produces higher quality surface finishes
- produces a more economical concrete because fly ash is less costly than cement

The Army Corps of Engineers has been the country's largest fly ash user for over 20 years. Most of the fly ash was used in mass concrete of which large structures such as dams and locks are built. Until recently, when dam building dropped to a low level, in a typical year the Corps placed 5 mission cubic yards of concrete containing 150,000 tons of pozzolan, most of which was fly ash. Fly ash was utilized in the Hoover Dam, the Barker Dam near Boulder, Colorado, the Hungry Horse and Canyon Ferry Dams in Montana, and the Sutton Dam in West Virginia to name a few (40:50-51).

Ready-mix concrete dealers are also adding fly ash to their concrete mixes as a cement replacement. As already mentioned, this not only represents a direct cost savings in materials, but the workability and pumpability of fly ash concrete reduce labor costs for the user (16:77).

Fly ash has also been used in the production of concrete pipe by the "packerhead" principle. Manufacturers have realized cost savings because the fly ash lubricants the mix so that production rises giving more pieces of pipe per hour. This lubrication also allows packer wings and long bottoms (equipment used to form the pipe) to last longer. The resulting pipe is more watertight and more resistant to the weak acids sometimes encountered in sewer lines (36:6).

Concrete block manufacturers using fly ash concrete have also realized similar benefits. The fly ash concrete gives required block strength and better mold life, no discoloration, better corners, and improved texture and finish (52:1).

Many industrial and commercial buildings and roads have been constructed with fly ash concrete. Some examples are: the C & S Bank Tower and the Hilton in Atlanta, Georgia; the Sears Tower; the John Hancock Building; and the 1st Wisconsin Bank

Building-Milwaukee. A survey of state highway departments in 1976 showed that 30 states were using or planning to use fly ash for concrete highways (17:11).

Structural Embankments and Fills

When used as a material in constructing embankments and structural fills, fly ash has two major advantages when compared to most natural soils and rocks: its availability in urban areas and its light unit weight. Fly ash is available as an alternate material where some natural materials are scarce, as in developed industrial areas. Since many power plants are being sited in these locations, fly ash, being locally available, may provide an economic alternative to natural soils. Its light unit weight, typically about 50 to 75 percent of the density of most soils, allows fly ash to be used with poor foundation soils or for landslide repair. The low unit weight of fly ash reduces the load on the weak foundation soils and the low density allows the use of a smaller tonnage of material for a given volume of fill. Fly ash also has a higher shear strength than some natural soils, especially silts and clays, and exhibits compaction behavior that is less sensitive to variations in moisture content (15:p.6-1).

The following examples illustrate the successful use of fly ash as a material for fill construction:

1. Ash was used to correct a landslide which affected part

of U.S. Route 250 west of Fairmont, West Virginia. Ash was used because of its light weight and higher shear strength than alternate available natural materials. The slide was repaired using 5,000 tons of fly ash.

2. Construction of a fill embankment near Montgomery, West Virginia provided building sites for a housing project. A total of 350,000 cubic yards of fly ash was used in the fill to raise the elevation of the 11- acre housing site. The fill ranged in thickness up to 11 feet.

Structural Backfills

Ash has been used as a backfill material for bridge abutments, walls, and other types of retaining structures. Its principle advantage is its low unit weight which, when combined with its relatively high shear strength, reduces the load to be used in the design of retaining structures. Other advantages of ash as a backfill are lower transportation costs and reduced settlement of underlying soils, both due to its lower unit weight, and its availability which can result in a lower acquisition cost than for alternate materials (15:p.7-1).

Following are two examples that illustrate the successful use of ash as a backfill material:

1. Bottom ash was utilized as a lightweight backfill against a collapsed retaining wall at the Cultural Center at the West Virginia

Capital Complex in Charleston. A 150-foot section of wall began failing and three factors led to a decision to use bottom ash to replace the original backfill material. They were its light weight (60-pounds per cubic foot), its permeability, and its low cost (34:2).

2. Fly ash was used as a backfill material for a 25 foot high, 230 foot long rigid retaining wall in Kansas City, Missouri. The wall was backfilled with 3,500 tons of self hardening fly ash. Fly ash was used to reduce the lateral pressure on the wall and, thereby, allow for a more economical design of the wall. A $39,000 savings was realized in the construction of the wall. The majority of the savings came from a reduction in the amount of concrete and reinforced steel needed for the wall due to the light unit weight and high shear strength of the compacted fly ash (15:p.7-2).

Road Construction

Fly ash, bottom ash, and boiler slag have been extensively investigated and used in areas where they are readily available. A survey of state highway departments in 1976 showed that 25 states were using or planning to use one or more of these coal ashes in road construction. The ash is used as an alternate source for the aggregates used in road construction and also for its pozzolanic properties.

Fly ash is utilized as a base course in cement-stabilized pavements. Cement, fly ash, and water are mixed and compacted. The resulting mixture hardens to form a surface with the load bearing capacity and durability (frost resistance) for base course applications (20:4).

Fly ash is also used as a mineral fill in bituminous concrete, which is commonly called asphalt. In the manufacture of asphalt pavements, the amount of liquid asphalt (bitumen) used is approximately only 6 percent by weight of the total product. The balance of the mix consists of gravel and sand. To produce a good, dense asphaltic pavement, a fine dust or mineral filler must be used. Mineral fills add strength, stability, plasticity, water resistance and weather resistance to the asphaltic pavement. Fly ash imparts all these qualities to the pavement; plus, as a filler of uniform fineness it reduces the number of voids in the mixture and thus economically reduces the bitumen requirements (52:2).

The West Virginia Highway Department uses bottom ash in a cold mix with emulsified asphalt for treatment of secondary roads. The use of emulsified asphalt makes heating and drying the mixture unnecessary, thus the reference to a cold mix. The bottom ash is loaded into the hopper of a mixing machine called a pugmill. Here it is mixed with a metered amount of emulsified asphalt, and either loaded directly into haul trucks for immediate use or stockpiled for future use (33).

Bottom ash and boiler slag are also used as aggregates in bituminous and concrete base courses and surface courses. An excellent example of the utilization of these ashes is the widening and relocation of a 4-mile-long portion of West Virginia Route 2. Bottom ash and boiler slag were used in all courses of the road. The bottom base course contains 45 percent cyclone slag, 42 percent bottom ash mixed with 5 percent Type I Portland cement and 8 percent water. The overlying base course is composed of 80-85 percent bottom ash and 15-20 percent AASHO #3 blast furnace slag. The surface course is bituminous concrete with boiler and blast furnace slag used as the aggregate (35).

Soil Improvement

Fly ash has been used in the reclamation of land covered by strip mine spoils and spoils from underground mining. Experiments have shown that fly ash mixed with coal refuse or mine spoils may raise the pH of acidic soils, and may add calcium and magnesium, as well as other trace elements to the soil. Fly ash application may also enhance the moisture retention ability of the mixture, increase the air capacity and, in certain cases, even improve the soil texture. With these improvements in the soil, certain plants are able to reproduce, obtain better root penetration, and survive in a soil that would not normally sustain their growth. Fly ash contains very little phosphorus and nitrogen and therefore is not useful as a substitute for fertilizer.

Problems do occur using fly ash. Some may contain toxic levels boron, but the toxicity of the boron diminishes with time due to leaching of the soil. For this reason, it is best to use weathered fly ash for soil improvement (28:817).

Filter Aid for Wastewater Treatment

The water pollution control plant in Cedar Rapids, Iowa, is able to use fly ash from the municipal power plant as a conditioning agent for sludge dewatering. The fly ash is used as a filter aid in a pressure filter. The filtered sludge and fly ash form a sludge cake that contains in addition to the chemicals in the fly ash, nitrogen, phosphorus, and potash. The addition of these chemicals gives the mixture some fertilizer value (21:44-45).

Lime Replacement for Flue-Gas Desulfurization Units

For conventional SO_2 lime-based removal systems installed to control utility stack pollution, the lime itself and its handling can be a significant cost item. Some fly ashes contain sufficient alkali to react with the SO_2 in the removal systems without the addition of lime. Engineering studies have shown that utilizing fly ash as a source of alkali is a viable alternative to conventional lime/limestone

SO_2 scrubbing. Economic benefits include: elimination of alkali cost; reduction in power consumption; reduction in initial capital investment; reduction in waste solids handling and disposal cost; and improved system reliability (23:61-63).

Refuse Pile Fire Abatement

Burning spoil piles are a common problem in coal mining regions. Fly ash has proven to be an effective material in refuse pile fire abatement. The fly ash is mixed with water to form a fly ash/water slurry that is injected through pipes driven into the burning zone. The fire is "snuffed" due to the blocking of annular spaces and crevices with the fly ash which remains in place after the water evaporates. The burning zone is cooled by the water and the heat capacity of the fly ash itself. On projects where steep slopes are burning or access to the burning area is difficult, fly ash injection has been shown to be the most economical and at times the only effective method of fire abatement (42:665-676).

Grouting Mixtures

Fly ash possesses properties and characteristics of value in grouting. The spherical shape of fly ash particles allows grout containing fly ash to be pumped more easily than those containing cement or cement and sand. The pozzolanic activity of fly ash also makes fly ash/cement mixes stronger than sand/cement grouting mixtures

(8:911-914).

Bricks

Fly ash brick, developed by the Coal Research Bureau at West Virginia University, can be manufactured with the expenditure of 20 to 50 percent less energy than clay brick. A typical composition for a fly ash brick consists of approximately 72 percent fly ash, 25 percent boiler slag and 3 percent sodium silicate. The savings in energy consumption results because the raw materials for fly ash brick don't have to be crushed as does clay for clay bricks. There is a fuel savings because fly ash brick can be fired in half the time required for clay brick. Fly ash brick are 10 to 20 percent lighter than clay brick which allows more bricks for a given weight to be shipped. The fly ash brick exceeds ASTM standards for grade severe weathering brick (46:85-88).

Recovery of Resource Materials

Several promising new processes for the recovery of aluminum, iron, and titanium from coal ash, primarily power plant fly ash, have been conceived and investigated at the Oak Ridge National Laboratory. These processes include direct acid leach, the salt-soda sinter process, and the calsinter process. The salt-soda sinter and calsinter processes can recover 95 percent of the aluminum and 90 percent of the iron and titanium in the coal ash (10:56-67; 31:4).

CHAPTER III

MODEL DEVELOPMENT

INTRODUCTION

In order to develop the procedure to determine the resource utilization potential of coal ash, it will be helpful to have a model to base the procedure upon. This model should determine what factors affect utilization potential, define the factors, and show how they interact. This chapter provides the model that will be used to develop the procedure described in the next chapter. The model, shown in Figure 3-1, was developed from the literature review in Chapter II. The information provided in this chapter will define the factors identified in the model and explain how they interact.

MODEL FACTORS

Resource Utilization Potential of Ash

The best way to define the meaning of the term resource utilization potential is to look at the definition of each of the words that make up the term. According to Webster's New World Dictionary of the American Language, the definitions for these words are:

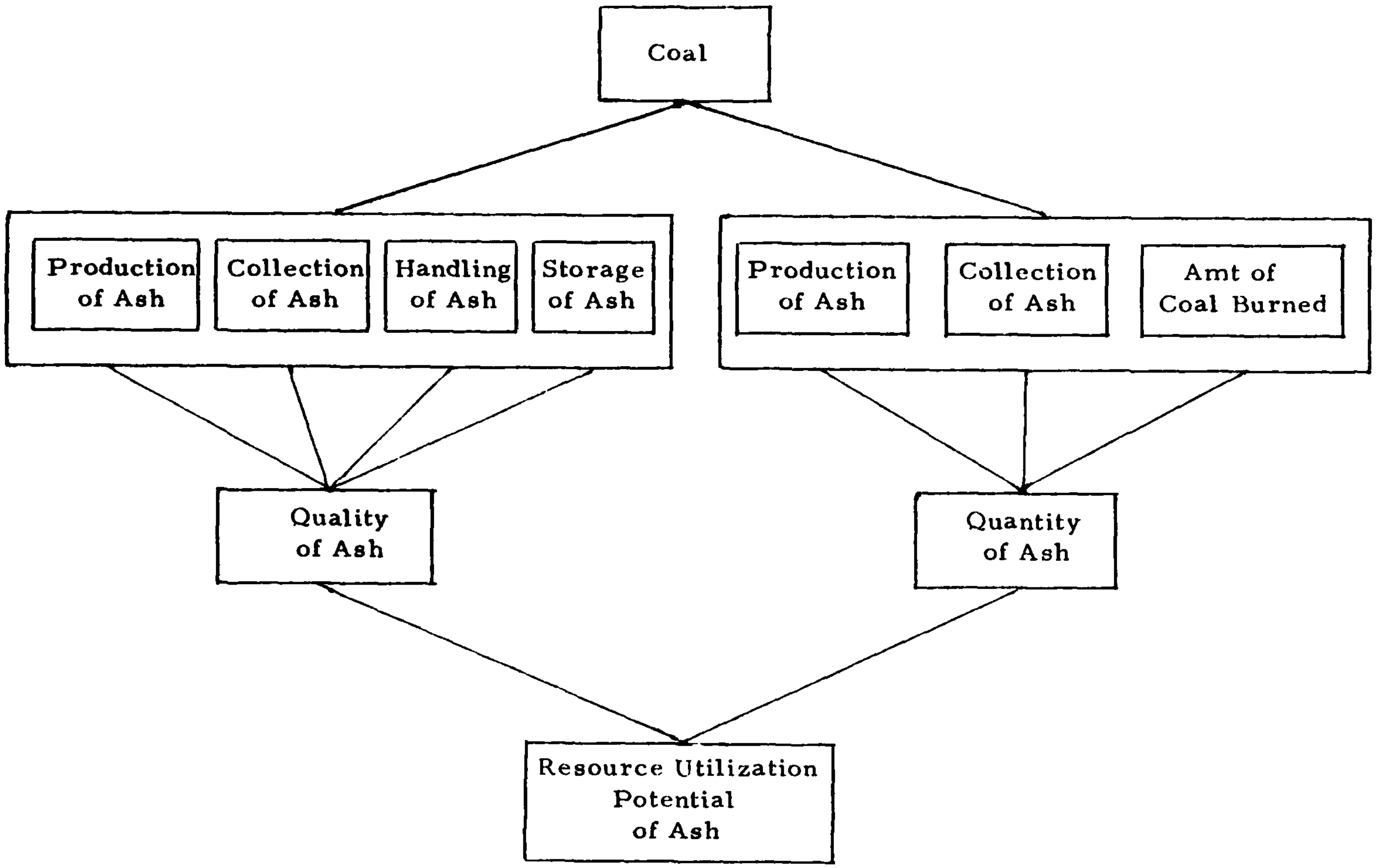

Figure 3-1: Coal Ash Resource Utilization Model

1. Resource--Something that lies ready for use or can be drawn upon for aid; supply of something to take care of a need.

2. Utilization--To put to use; make use of; get profit or benefit from by using.

3. Potential--That can, but has not yet, come into being; possible; latent; unrealized; undeveloped; opposed to actual.

As these words apply to the model factor labeled Resource Utilization Potential of Ash, the definitions are expanded as follows:

1. Resource--Coal ash is listed as the sixth most abundant solid mineral according to figures compiled by the U.S. Department of the Interior for their annual Minerals Yearbook. The latest figures show ash behind sand/gravel, stone, coal (all types), iron ore, and Portland cement (49;16:69). Two states, Maryland and Massachusetts, have enacted legislation that classifies coal ash as a natural resource (16:74).

2. Utilization--The environmental benefits and the energy and resource savings realized from the utilization of coal ash were identified in the Overview of Chapter I.

3. Potential--The potential of coal ash is realized in the ability to use it as an alternate material. Most of the laboratory experimentation, field testing, and actual applications for coal ash have been in the construction industry. The success of this work has been validated by the establishment of material standards and

specifications for coal ash.

From the dictionary and expanded definitions of the words that make up the term resource utilization potential, the term may be defined as follows: The term resource utilization potential, as used in this report, refers to the possibility for a coal ash to be used as a material resource as defined by the material standards that pertain to the particular utilization of the coal ash.

The standards that the coal ash must satisfy are either a test of the coal ash itself or a test of a composite material of which the coal ash is a part. Organizations such as the American Society for Testing and Materials (ASTM) publish accepted and standardized testing procedures. Also, there are Federal, state, and local agencies that publish their own testing standards and specifications. The U.S. Army Corps of Engineers is an example of a Federal agency. On the state and local level, most highway departments have standards and specifications that may employ ASTM standards or standards and specifications developed to meet their own particular needs.

The physical and chemical properties of the coal ash are used to determine whether or not the ash has a resource utilization potential for the particular utilization category to which the standards apply. Appendix C contains ASTM standards for some of the utilization categories identified for coal ash in Chapter II.

Two factors that affect the resource utilization potential of coal ash are the quality and quantity of the ash.

Quality of the Ash

The quality of the ash refers to the intrinsic character of the ash as defined by its chemical and physical properties. The measurement of these properties against standards and specifications such as those published by the American Society for Testing and Materials determines the quality of the ash and thus its suitability for a specific use (26:94).

The principal constituents of coal ash for which chemical analyses are commonly performed are (15:p.4-28):

- Silica, SiO_2
- Alumina, Al_2O_3
- Iron Oxide, Fe_2O_3
- Magnesium Oxide, MgO
- Sodium Oxide, Na_2O
- Potassium Oxide, K_2O
- Sulfur Trioxide, SO_3
- Titanium Dioxide, TiO_2
- Phosphorous Pentoxide, P_2O_5
- Calcium Oxide, CaO
- Carbon (usually determined by loss-on-ignition)

The principal physical properties of coal ash for which analyses are commonly performed are (15:p.3-1):

- grain-size distribution
- moisture content
- density
- shear strength
- compressibility

- permeability
- capillarity
- frost susceptibility
- specific gravity

Whether or not all or some of these properties, or other properties, are tested for depends upon the specifications of the particular standard for which the utilization potential is being examined.

For example, a designer of a structural fill would want to know the chemical composition of the ash being used because of its effect on the physical characteristics of the ash. The carbon content of the ash will affect its ability to act as a pozzolan, its specific gravity, its color, and optimum moisture content. A high carbon content will inhibit the hardening mechanism of the ash, will generally lower the specific gravity, will make the ash darker in color, and will raise the optimum moisture content for compaction. A high calcium oxide, sodium oxide, or potassium oxide content will enable the ash to self-harden when moisture is added. A high sulfur trioxide content will indicate the possibility of sulfate problems for any concrete structures placed in contact with the ash. The leachable calcium oxide and iron oxide contents of the ash will influence the pH of the leachate. In general, a high calcium oxide content creates an alkaline leachate and a high iron oxide content creates an acidic leachate (15:p.4-29).

See Appendix C for ASTM standards and specifications that are applicable to coal ash.

Quantity of the Ash

The quantity of ash refers to the amount of ash produced by type from a particular power plant or heating plant. The amount of ash is divided between fly ash and either bottom ash or boiler slag, depending upon the type of furnace and collection system used. The unit of measure for ash production that was commonly used in the literature reviewed for this report was tons per day. However, units such as pounds per day or tons per month may be more applicable in instances where small tonnages of coal are burned.

The important point is that the amount of coal ash available has a significant impact on the potential marketability of the ash as a resource. Recall from Chapter II that coal ash is used mainly as an alternate material in the construction industry where large tonnages of the material are required. It is possible for a coal ash to satisfy the quality standards, but lose its resource utilization potential because the demand for the quantity of ash required cannot be satisfied (11;24).

The demand for coal ash is also seasonal. This is due to the fact that the construction industry is more active during the summer than the winter months (11).

The resource utilization potential of an ash that meets quality standards may be realized if the ash is stored in a manner that will not adversely affect the qualities that determined its potential. In this manner, ash may be stockpiled over a period of time to satisfy specific quantity demands (16:74).

Factors that Affect Quality and Quantity of Ash

The factors that affect the quality and quantity of the coal ash are as follows (13:p.2-1; 15:p.3-1; 16:2):

- feed coal
- amount of coal burned
- ash production method
- ash collection method
- ash handling method
- ash storage method

Feed coal. The composition of the coal ash is primarily a function of the elemental composition of the feed coal. The major elements comprising coal are carbon, hydrogen, oxygen, nitrogen, and sulfur. They generally account for 90-97 percent of the total and are present in varying quantities. When burned, all the major elements form gaseous compounds that are mostly discharged in the flue gases. Thus they have little bearing on the composition of the ash.

Trace elements and minor constituents in coal may come from a number of sources. Some of these elements may have been in the vegetation from which the coal was formed, or from erosion and other geological processes during and after the formation of the coal. Most of the trace elements and minor constituents are not combustible and remain in the ash (13:p.2-2).

Table 3-1 illustrates the trace element levels in coals which have been categorized by region. It is evident that the elemental composition of a coal can vary greatly due to its geographic source. It may also vary from one type of coal to another. Table 3-2 shows the range of trace element levels found in U.S. coals.

The amount of ash generated by a furnace is a function of the ash content of the coal. Typical ash contents vary from 3 to 30 percent. In general, higher grades of coal will have a lower ash content than lower grades; however, there are exceptions (13:p.2-2). Figure 3-2 illustrates the ASTM Coal Classification Index which defines the various coal grades. Although various grades are shown, the main grades that most people are familiar with are: anthracite, bituminous, subbituminous and lignite. The variation of the ash content of coal by rank and geographic source is illustrated in Table 3-3.

The elemental composition and ash content of the mined coal are affected by coal preparation processes that include: crushing, washing, and pulverization. Crushing produces a coal of uniform size, exposes more of the impurities in the coal, and allows more combustion efficiency by increasing the surface area of a given amount of coal. Washing the crushed coal reduces the ash and sulfur content

TABLE 3-1

AVERAGE TRACE-ELEMENT CONTENTS FOR COALS FROM VARIOUS REGIONS OF THE U.S. [25; 13:p.2-3]

Element	SWI[a]	EI[b]	NGP[c]	APP[d]
Boron	33	96	116	25
Beryllium	1.1	2.5	1.5	2.5
Cobalt	4.6	3.8	2.7	5.1
Chromium	13	20	7	13
Gallium	2.0	4.1	5.5	4.9
Germanium	5.9	13	1.6	5.8
Lanthanum	6.5	5.1	9.5	9.4
Molybdenum	3.1	4.3	1.7	3.5
Nickel	14	15	7.2	14
Tin	1.3	1.5	0.9	0.4
Titanium	250	450	591	350
Vanadium	18	35	16	21
Yttrium	7.4	7.7	13	14
Zinc	108	44	59	7.6

[a] SWI = Forty-eight coals from Western and Southwestern Interior Region.

[b] EI = Eastern Interior Region, 53 coals.

[c] NGP = Northern Great Plains Region, 51 samples.

[d] APP = Seventy-three coals from Appalachian Region.

TABLE 3-2

RANGE OF TRACE ELEMENTS IN U.S. COALS
[25; 13:p.2-4]

Element	Range (ppm)
Beryllium	0 - 31
Boron	1.2 - 356
Fluorine	10 - 295
Phosphorus	5 - 1430
Scandium	10 - 100
Vanadium	0 - 1281
Chromium	0 - 610
Manganese	6 - 181
Cobalt	0 - 43
Nickel	0.4 - 104
Copper	1.8 - 185
Gallium	0 - 61
Germanium	0 - 819
Arsenic	0.5 - 106
Selenium	0.4 - 8
Bromine	4 - 52
Yttrium	<0.1 - 59
Zirconium	8 - 133
Molybdenum	0 - 73
Cadmium	0.1 - 65
Tin	0 - 51
Antimony	0.2 - 9
Lanthanum	0 - 98
Mercury	0.01 - 1.6
Lead	4 - 218
Uranium	<10 - 1000

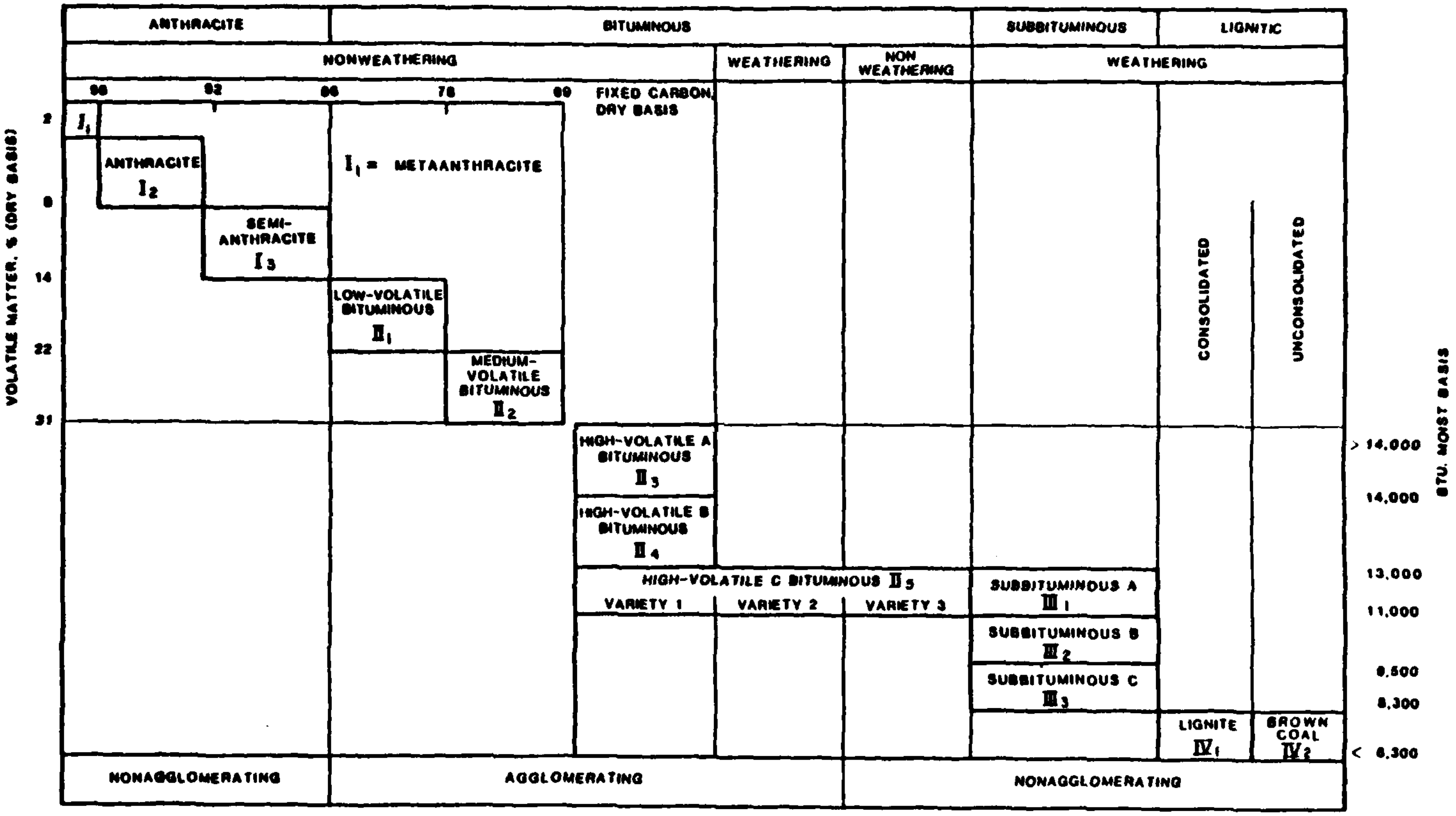

Figure 3-2: ASTM Classification of Coals by Rank [41; 13:p.2-5]

TABLE 3-3

PROXIMATE ANALYSIS OF SOME NORTH AMERICAN COALS, ON A DRY BASIS

(13:p.2-9)

Rank and Source	Ash (Percent)	Volatile Matter (Percent)	Fixed Carbon (Percent)	Heat Value (Btu/lb)
Lignite:				
Montana	9.8	42.9	47.3	10,528
N. Dakota	8.1	44.6	46.4	11,399
S. Dakota	13.8	40.6	45.6	10,373
Texas	11.0	44.2	44.8	11,083
Ontario	13.9	56.7	30.0	9,906
Saskatchewan	10.1	36.1	53.8	11,392
Subbituminous:				
Wyoming	4.7	43.9	51.4	12,248
Alberta	7.4	39.2	53.4	12,812
Bituminous:				
Utah	6.1	42.9	51.0	13,535
Illinois	9.9	44.2	45.9	12,515
British Columbia	12.1	37.3	50.6	12,529
Alberta	7.7	34.7	57.7	12,559
Pennsylvania	5.5	37.2	57.3	14,217
Alabama	7.8	36.5	55.7	13,884
Nova Scotia	8.8	33.5	57.7	13,896
Anthracite:				
Pennsylvania	11.9	9.6	78.5	13,474

of the coal. Clean coal has a higher energy density and will produce less ash and impurities when burned. Pulverizing the coal before burning allows for a greater combustion efficiency than that obtained with crushed coal (38:45; 44:148).

Amount of coal burned. The amount of coal burned in the furnace is a direct function of the amount of ash that will be produced. The more coal burned; the more ash produced. As previously mentioned, the amount of ash that will be produced depends upon the ash content of the feed coal.

Production of ash. This factor refers to the type of furnace used to burn the coal. The discussion in Chapter II mentioned three types of furnaces:

- pulverized coal-fired furnaces
- cyclone furnaces
- stoker-fired furnaces

The type of furnace will affect both the quality and quantity of the ash.

The fly ash which is produced by stoker-fired furnaces is coarser than the fly ash produced by either pulverized coal-fired or cyclone furnaces (13:p.2-11). Approximately 90 percent of the fly ash which leaves the cyclone furnace in the stack gases is finer than 0.010 mm. The percentages of fly ash finer than 0.010 mm for pulverized coal and stoker furnaces are 65 percent and 5 percent respectively. The carbon content of the ash from pulverized coal-fired furnaces is lower than that of the other two furnaces because the pulverization of the coal allows a more complete combustion.

The type of furnace combined with the collection system for the ash that falls to the bottom of the furnace, determines the quantities of fly ash and bottom ash/boiler slag that will be produced. The pulverized coal-fired furnace is designed for a particular method of ash removal, depending on the fusion temperature of the ash and the variation of furnace temperature with boiler load (13:p.2-10). Ash fusion temperatures above 1800° to 2200° F favor dry-bottom removal systems. Lower ash fusion temperatures favor a wet-bottom removal system. Figure 3-3 illustrates the quantities of fly ash and bottom ash/boiler slag produced by each type of furnace.

Collection of ash. This factor refers to the method used to collect the ash produced in the furnace during the combustion process. The bottom ash/boiler slag is collected at the bottom of the furnace and the fly ash is collected from the flue gases exiting the top of the furnace.

The dry and wet-bottom collection systems for bottom ash and boiler slag respectively were already mentioned in the discussion of furnaces. The ash from the wet-bottom system (boiler slag) is composed of black angular particles having a glassy surface texture.

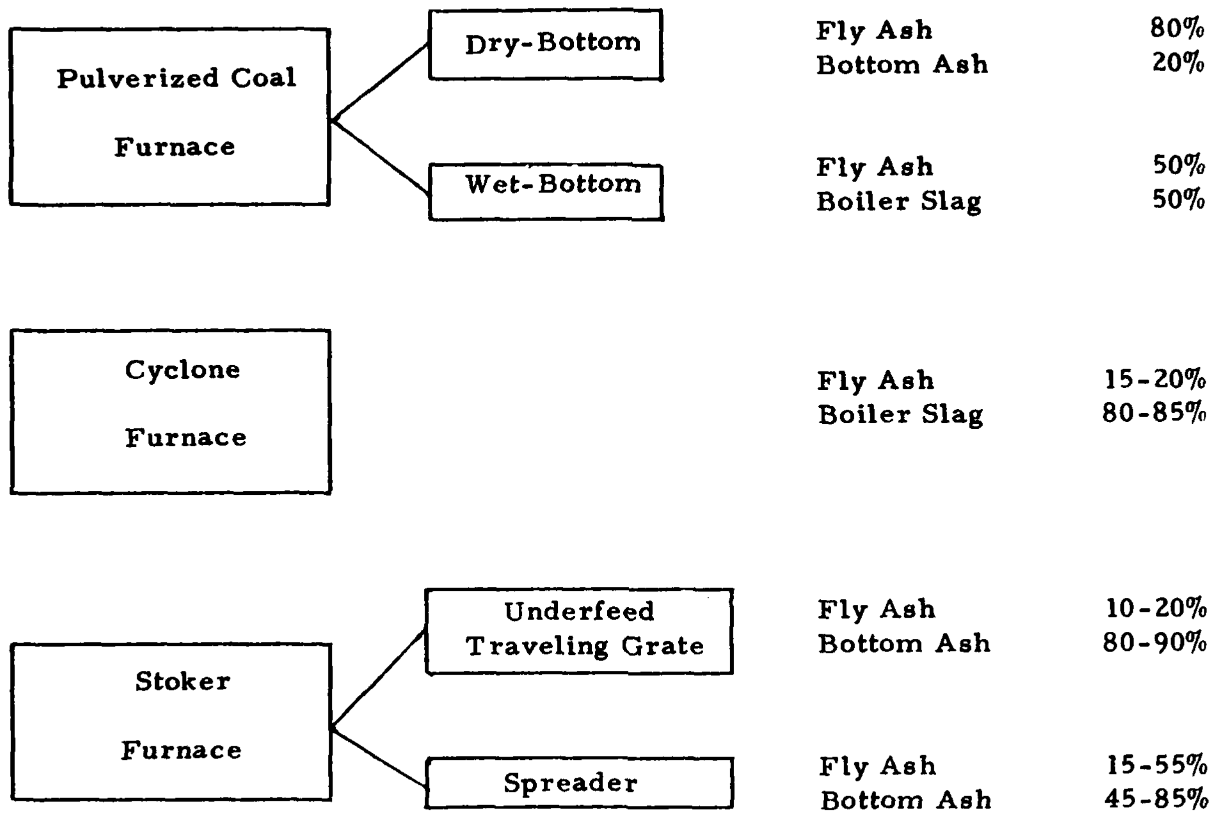

Figure 3-3: Quantities and Type of Ash as a Function of Furnace Design

Whereas, the ash from the dry-bottom system (bottom ash) is composed of angular particles that are gray to black in color with a porous surface texture (47:248).

The various methods for collecting fly ash were discussed in Chapter II. One effect that the type of collection equipment has on the fly ash collected is the grain-size distribution of the ash. Typically, the fly ash from an electrostatic precipitator or venturi scrubber will have a similar gradation while fly ash from a cyclone collector will have a coarser gradation due to the respective collection effeciencies of the units (13:p.2-13).

Fly ash collection systems may also be categorized between wet and dry systems. The use of water in the collection system will affect some of the chemical properties of the fly ash. The water will dissolve some of the fly ash particles and the chemical deposits on the surface of other fly ash particles (13:p.2-13).

Handling of ash. This factor refers to the method used to convey the ash to the storage area. Wet and dry methods were discussed in Chapter II. As with the collection system, using water in the handling system will dissolve some of the ash particles and the chemical deposits on the surface of other ash particles.

Storage of ash. This factor refers to the method used to store the ash. The method of storage can have a great influence on the quality of the ash and thus its utilization potential (15:p.2-10). Wet and dry storage methods were discussed in Chapter II.

The wet method of storage involves the addition of large quantities of water to the ash to create a slurry. As previously mentioned, the soluble portion of the ash may be completely or partially dissolved due to the interaction with the water. Ashes with a high calcium oxide or sodium oxide or potassium oxide content will harden when mixed with water (16:75). Ash stored in ash ponds may have an undesirable gradation because the lighter particles do not settle to the bottom of the pond as fast as the heavier particles. The heavier particles will collect close to the slurry discharge point and the lighter particles furthur away toward the opposite end of the pond.

The dry method of storage involves the use of silos, landfills, and stockpiles of ash. Silo storage has the least adverse impact on the quality of the ash. Most fly ash that is utilized is obtained from dry silos (15:p.2-10). Bottom ash and boiler slag stored dry has proven to be easier and more economical to recycle than ash stored wet (16:74).

The mixing of fly ash and bottom ash for storage may produce undesirable gradations in the composite ash mixture and adversely affect the utilization potential of the ash (15:p.2-10; 50:155).

At many power plants bottom ash and boiler slag are placed in long-term storage by end dumping into stockpiles. In steep piles, the more coarse ash tends to fall to the bottom of the pile. This method is satisfactory as long as the segregation is controlled (50:155).

SUMMARY

The resource utilization potential of a coal ash is defined as the possibility for the ash to be used as a material resource. The ash must satisfy designated material standards for quality and must also be available in sufficient quantity for a particular use. Factors that affect the quality and quantity of the ash are: the coal, amount of coal burned, and the production collection, handling and storage methods. This chapter has provided a model that captures all of these factors.

The next chapter will provide a procedure for determining the ash utilization potential of a coal ash.

CHAPTER IV

THE PROCEDURE

INTRODUCTION

The analytical procedure discussed in this chapter is based upon the model developed in Chapter III. Whereas, the model was developed by starting with a definition of resource utilization potential and working backward to capture the factors that influence the utilization potential of coal ash; the procedure described in this chapter starts with an analysis of the factors described in the model to determine the resource utilization potential of a coal ash.

The procedure starts by describing the present conditions at the heat plant. That is, the coal, amount of coal burned, and the production, collection, handling, and storage methods. These factors are used to determine the quality and quantity of the coal ash.

DESCRIPTION OF PRESENT SYSTEM

The first six steps of the procedure involve gathering data to describe the present system for coal consumption and ash production. This data serves as a basis to aid in determining the quality and quantity of the ash.

Feed Coal

Step 1 is to identify the type of feed coal burned in the furnace. The information required is the:

- coal rank
- geographic source
- ash content

This information can be obtained from the coal analysis report included with the base coal contract. The base contract administration office will have a copy of the report and contract. Two other offices may possibly have a copy of the coal analysis. They are the financial management and environmental planning sections in the civil engineering squadron.

Amount of Coal Burned

Step 2 is to determine the amount of coal that is burned during the year. Coal consumption at a central heat plant is not constant throughout the year. More coal is consumed during the cold winter months than during the warmer summer months. Table 4-1 shows the yearly coal consumption by month for Wright-Patterson AFB, Ohio. The financial management branch for the civil engineering squadron should have this information. Current coal consumption data can be obtained from the manager of the central heat plant.

Ash Production Method

Step 3 involves determining the type of furnace used in the

TABLE 4-1

FIVE YEAR COAL CONSUMPTION
WRIGHT-PATTERSON AFB, OHIO

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
1980	12,759.99	12,259.60	11,644.17	7,959.93	4,217.62	3,184.21	3,128.98	3,208.53	2,971.25	7,296.89	7,458.38	12,058.13	87,547.68
1979	16,016.73	14,592.11	11,321.37	9,104.18	4,594.36	3,259.32	2,744.60	2,839.98	2,909.04	7,467.72	9,601.04	13,028.49	97,478.94
1978	19,290.74	16,596.50	14,491.97	7,204.35	4,179.19	3,200.53	2,653.69	2,582.68	3,030.65	7,715.19	11,444.26	17,002.78	109,392.53
1977	19,515.48	14,050.85	11,898.09	7,386.63	3,781.99	3,112.70	2,667.72	3,005.08	3,615.66	8,412.95	13,258.63	16,720.30	107,426.08
1976	17,120.60	12,727.18	10,859.36	8,284.78	7,160.92	4,048.07	3,050.65	2,903.71	3,655.99	6,762.25	10,043.75	14,205.92	100,823.18

Source: 2750th Civil Engineering Squadron Financial Management Branch central heat plant. This step and the next three steps can be best accomplished by visiting the central heat plant and talking with the plant manager. Determine the type of furnace from the following list:

- pulverized coal--wet bottom
- pulverized coal--dry bottom
- cyclone
- spreader stoker
- traveling grate stoker
- underfeed stoker

Information required is the furnace type and percentage of fly ash and bottom ash/boiler slag produced. See Figure 3-3 in Chapter III for the ash percentages.

Ash Collection Method

Step 4 involves determining the type of collection system employed for the fly ash and bottom ash/boiler slag. Table 2-1 in Chapter II lists the types of collectors for fly ash along with the respective collection efficiencies. The information required is the:

- type collector
- overall collector efficiency

The type of furnace identified in Step 3 will determine whether the ash from the bottom of the furnace is bottom ash or boiler slag. Refer to Figure 3-3 for the ash type. The information required is the type of ash:

- bottom ash
- boiler slag

Ash Handling Method

Step 5 involves determining how the ash is handled. The fly ash and bottom ash/boiler slag may be handled mixed or separate. The ash may also be handled wet or dry. Determine how the ash is conveyed from the collectors to temporary and/or permanent storage locations. The information required is:

- ash handled separate or mixed
- ash handled wet or dry

Ash Storage Method

Step 6 involves determining how the ash is stored. The ash may be stored using wet and/or dry methods. Also, fly ash and bottom ash/boiler slag may be stored separately or mixed. Ash stored wet will be in an ash pond. Ash stored dry may be in a silo, stockpile, or landfill. Silo storage is usually for fly ash on a temporary storage basis. Determine how the ash is stored. The required information is:

- ash stored wet or dry
- ash mixed or separate

DETERMINATION OF QUANTITY

The quantity of ash produced is determined by the amount of coal burned, ash content of the coal, furnace type, and the collection system efficiency. This data was obtained in steps 1 through 6 of the procedure. The next three steps show the calculations necessary to obtain the quantity of ash produced from the above data. The steps for determining ash quantities follow.

Total Ash

Step 7: calculate total ash produced

total ash = coal consumption x % ash content

Fly Ash and Bottom Ash/Boiler Slag Quantities

The furnace type and collection systems listed in Figure 3-3 and Table 2-1 contain the percentage figures for the calculations.

Step 8: calculate fly ash collected

total fly ash = total ash x % fly ash

fly ash collected = total fly ash x overall collector efficiency

Step 9: calculate bottom ash/boiler slag collected

bottom ash collected = total ash x % bottom ash

The above calculations are heuristic in nature. This means that the solutions for these calculations are not exact. They are approximations that result in solutions that are close enough for initial assessment purposes. The calculations for steps 8 and 9 may be verified by actually weighing the ash and, if necessary, adjusting the percentages to obtain more accurate results.

DETERMINATION OF QUALITY

The last step of the procedure, Step 10, involves the sampling and testing of the ash. Obtaining adequate and representative samples for laboratory testing is as important as conducting the tests accurately. Once the samples are taken, tests must be accomplished to determine the chemical and physical engineering properties of the ash. The results of the tests are then used to help determine the resource utilization potential of the ash. The best method to determine the chemical and physical properties of the ash is to have the analysis run by a professional testing laboratory. A laboratory with previous experience in testing coal ashes would be excellent.

Sampling

Sampling is equally as important as the testing, and the sampler should use every precaution to obtain samples that will show the true nature and condition of the materials which they represent (6: 567). The sampling points for the fly ash and bottom ash/boiler slag will depend upon the handling and storage methods employed at the heat plant. If the two ashes are handled and stored separately, samples may be taken from the storage area for each. If the two ashes are mixed during handling and/or storage, the mixture may be sampled for testing for utilization potential. Otherwise, samples must be taken at a point in the system before the two ashes are mixed. The heat plant supervisor should be able to help determine the proper sampling points in the system.

If the ash is held in a temporary storage point such as a silo or dewatering bin before being transferred to a final disposal point, the ash may be sampled for testing from both the temporary and final storage points. Exposure to the elements and storage procedures at the final storage point may affect the properties, both physical and chemical, of the ash.

To assure that samples are representative, ASTM has developed sampling procedures. Two sampling procedures that refer to sampling from bulk storage are ASTM Designation D75, "Standard Methods of Sampling Aggregate" and C311, "Sampling and Testing Fly Ash for Use as an Admixture in Portland Cement Concrete." These standards outline the procedure for sampling from conveyors, discharge chutes from bulk storage, sampling tubes from bulk storage, stockpiles, and train cars or trucks. A brief explanation of each sampling procedure will follow (6):

<u>From conveyors</u>. When sampling from a conveyor belt, take at least three approximately equal increments, selected at random, from the unit being sampled. The sample should weigh at least four pounds. This amount may be secured by taking the entire test sample in a single operation, known as the "grab method," or by combining

several portions taken at regular intervals known as the "composite method." Stop the conveyor belt while the samples are being taken. Insert two templates, the shape of which conforms to the shape of the belt, and space them such that the material contained between them will yield the desired weight. Carefully scoop all material between the templates into a suitable container and collect the fines on the belt with a brush and dust pan and add to the container.

Discharge chutes from bulk storage. Take samples by either the "grab" or "composite" method. Take each increment from the entire cross section of the material as it is being discharged. The sample should not include the initial discharge from a newly filled bin. It is usually necessary to have a special device constructed for use at each particular installation. This device consists of a pan of sufficient size to collect the entire cross section of the discharge stream and hold the desired quantity of the material without overflowing. A set of rails may be necessary to support the pan as it is passed under the discharge stream. Take samples only from bins that are full, or nearly so, to minimize the chance of obtaining segregated material.

Sampling tubes from bulk storage. This method may be employed when the depth of the material to be sampled does not exceed ten feet. The samples are obtained by inserting the sampling tubes vertically to the full depth of the material. The samples should be taken from points well distributed over the area of the storage.

Stockpiles. Avoid sampling from stockpiles whenever possible, particularly when the sampling is done for the purpose of determining aggregate properties that may be dependent upon the grading of the sample. If the sample must be taken from a stockpile, design a sampling pattern for the specific case under consideration. In selecting sampling points, it is important to sample only those portions of the stockpile that will be used, or if all of the pile is to be used, then samples from throughout the pile are required.

Train cars or trucks. In the case of sampling from train cars or trucks, where the material is from the same source, samples may be combined from multiple cars or trucks to form a test sample. A suggested method for sampling from individual cars or trucks is as follows:

> Dig holes as deep and as narrow as possible--not less than 12 inches in depth--at distances about one-sixth along the diagonal line drawn from the corners of the wagon. Also dig a hole at the centre of the wagon. Slope the holes so as to leave a nearly vertical wall nearest the centre of the wagon and obtain the increment by scraping the scoop up the face of this wall from bottom to top [19:223].

A standard procedure does not exist for sampling ash which is stored in an ash pond due to the fact that construction materials are not generally stored in this manner. Sampling from the ash pond will not proceed until the pond is filled to capacity and the effluent

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A PROCEDURE FOR DETERMINING THE RESOURCE UTILIZATION POTENTIAL --ETC(U)
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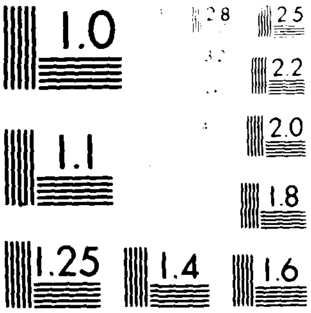

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

has drained off. When sampling from an ash pond, it is important to collect a large enough number of samples to adequately estimate the properties of the entire ash supply that will be used. Because of differential settling, particle segregation, or changes in properties of the ash produced at different times, the location of the ash in the pond will have a significant influence on the properties of the ash (15:p.4-2). In selecting samples, it is important to sample only those portions of the ash supply that will be utilized. If the entire supply is to be utilized, then samples from throughout the ash pond will be required. A deep ash pond (over ten feet) can be sampled using core sampling tools similar to those used for soil testing. As with any sampling plan, common sense and good judgement combined with recommended sampling procedures are required to obtain representative samples of the material to be analyzed.

Analysis of Chemical Properties

A professional chemical testing laboratory should be employed to analyze the chemical properties of the ash. The analysis of the ash should test for the presence and amount of the following major constituents:

- silica
- alumina
- iron oxide
- magnesium oxide
- sodium oxide

- potassium oxide
- sulfur trioxide
- titanium oxide
- phosphorous pentoxide
- calcium oxide
- carbon

If there is a particular utilization potential identified from Chapter II that may be applicable near the base, the engineer may request that the testing laboratory analyze the ash so that it can be compared to a particular ASTM standard to determine its utilization potential. As an example, ASTM C595, "Standard Specification for Blended Hydraulic Cements," would be used to determine the potential for using the ash in cement.

Analysis of Physical Properties

A professional materials testing laboratory should be employed to analyze the physical properties of the ash. Three physical properties that should be analyzed are the:

- grain-size distribution
- moisture content
- density

These are common to many of the standards used to determine the physical properties of a material. As with the chemical analysis, the testing laboratory will be able to use more specific testing standards if the ash is analyzed for a particular resource utilization. If the base engineer does not wish to test the ash for any specific utilization identified in Chapter II, the physical properties listed in Chapter

III may be analyzed. See Appendix C for ASTM standards and specifications that are applicable to coal ash and also the standard test package suggested on page 92 of the next chapter.

FINDING POTENTIAL ASH USERS

The discussion in Chapter II identified the resource utilization applications that have been employed using coal ashes. Some of the potential users of coal ash from that discussion are:

- cement manufacturers
- concrete block manufacturers
- concrete pipe manufacturers
- brick manufacturers
- grouting manufacturers
- ready-mix concrete suppliers
- construction contractors

The construction contractors of interest are those contracting for road, landfill, embankment, backfill, and concrete projects.

The yellow pages of the local phone book are a good starting point to identify potential ash users. Also, a review of possible uses for the coal ash "in-house" at the base may be rewarding. Companies that specialize in coal ash marketing do exist. In situations where the capability for analysis does not exist, these companies may be hired as consultants to analyze the resource utilization potential of the coal ash and also market the ash if applicable.

If a potential ash user is contacted and shows interest in using the ash; then, the material standards of the ash can be defined.

A testing laboratory may then be employed to determine whether or not the ash meets the applicable standards for the potential utilization.

SUMMARY

The discussion in this chapter provides a ten step procedure that will aid a base engineer in determining the resource utilization potential of the coal ash produced at the base. The first nine steps may be accomplished by the engineer. They involve describing the present system for coal consumption and ash production at the base and determining the quantity of ash collected. The last step involves determining the quality of the ash. A professional testing laboratory is required for the majority of the work required in this step. The test results will allow the base engineer to compare the ash against existing material standards to help determine its resource utilization potential. The next chapter will demonstrate the use of the procedure.

CHAPTER V

TEST CASE

INTRODUCTION

The purpose of this chapter is to validate the procedure presented in Chapter IV by providing an example of how the procedure is used. The extent of the validation will be to insure that the data required as inputs to the procedure can be obtained from the information sources outlined in the previous chapter. The procedure will be followed exactly as outlined up to the point of actually testing the samples of ash. A total evaluation would include actual testing of the ash with subsequent utilization. This would require economic considerations that are beyond the stated scope of the research. However, two possible courses of action that can be employed to select test procedures and identify potential ash markets will be discussed. The heat plant (Building 1240) at Wright-Patterson AFB, Ohio, was used for the test case.

DESCRIPTION OF PRESENT SYSTEM

Step 1

The first step of the procedure involves the identification of the feed coal used to fire the boilers. A copy of the coal contract for Wright-Patterson AFB was reviewed at the base contract administration office. The following information required as data for the procedure was obtained:

- coal rank - bituminous
- geographic source - Kentucky and West Virginia
- ash content - 7%

This information was also available from the financial management branch and environmental planning section of the civil engineering squadron.

Step 2

This step involves determining the amount of coal that is burned per unit of time. As discussed in the previous chapter, whatever time period is convenient may be used. For this test case, the amount of coal burned per month was tabulated for the first half of 1981 and summed to obtain a six month total. A twelve month total would be more useful for an engineer actually utilizing this procedure; however, in the interest of using the most current information for the test case, it was felt that a six month period would serve the purpose of showing that the data may be obtained as outlined in Chapter IV.

Coal consumption records are maintained at the heat plant and are also available from the financial management branch in the civil engineering squadron. The coal consumption figures for the first six months of 1981 are:

Month	Coal Burned (tons)
Jan	14,223
Feb	11,920
Mar	11,343
Apr	6,378
May	5,075
Jun	3,322
Total	52,161

In order to accomplish the next four steps, the engineer should complete a tour of the heat plant.

Step 3

This step requires the identification of the type of furnace used to burn the coal. This information will allow the engineer to approximate the percentages of fly ash and bottom ash/boiler slag that will comprise the total amount of ash produced. He will also be able to determine whether the ash collected at the bottom of the furnace is bottom ash or boiler slag.

A tour of the heat plant, conducted by the heat plant supervisor, revealed that the type of coal-burning furnace used at Wright-Patterson AFB is a traveling-grate stoker. A review of Figure 3-3 showed that this type of furnace produces fly ash and bottom ash with the ash percentages split 10 to 20 percent fly ash and 80 to 90 percent bottom ash.

Step 4

This step involves determining how the ash is collected. The fly ash from the stoker-fired furnaces at Wright-Patterson AFB follows two paths as it rises from the bed of burning coal. The lighter fly ash particles exit the top of the furnace with the flue gases and are collected from the flue gas stream by electrostatic precipitators. The heavier fly ash particles are recirculated to a large hopper above the furnace and injected back into the furnace onto the bed of burning coal to allow for a more complete combustion of these particles. The injected fly ash may either escape from the bed of burning coal and exit the top of the furnace in the flue gas stream for collection by the electrostatic precipitator, or may remain on the bed of coal and be collected with the bottom ash. By definition, the injected fly ash particles that are not light enough in weight to exit the furnace in the flue gas stream are technically classified as bottom ash. The bottom ash falls from the end of the traveling grate into hoppers located below the furnace. Table 2-1 shows the overall collection efficiency of the electrostatic precipitator to be 97 percent.

Step 5

This step involves determining how the ash is handled. Whether the ash is handled wet or dry and mixed or separate will have an impact upon the physical and chemical properties of the ash.

Knowing how the ash is handled from the collection points to the temporary and permanent storage points will also aid in the selection of sampling points.

The ash is conveyed from collection points to storage points in the heat plant by a vacuum system. The ash is handled dry. The fly ash and bottom ash are conveyed separately to fly ash hoppers below the electrostatic precipitators and bottom ash hoppers below each furnace. Each is then conveyed separately to a temporary storage silo where the fly ash and bottom ash are mixed. Handling the ash dry precludes affecting the chemical properties of the ash through dissolution by water.

Step 6

This step involves determining how the ash is stored. Whether the ash is stored wet or dry and mixed or separate will have an impact on the physical and chemical properties of the ash. Knowing how the ash is stored will also aid in selecting sampling techniques for collecting ash samples.

All coal ash at Wright-Patterson AFB is stored dry. The fly ash and bottom ash are stored separate in their respective hoppers and are stored mixed in a temporary storage silo before being transported to the final storage site for disposal. Due to the mixing of the ash in the temporary storage silo, the permanent storage for the ash is also mixed. The permanent storage site is actually a disposal site. The mixed ash is conveyed to the disposal site by open dump trucks and spread over the ground in a manner similar to that of a landfill operation. The mixing of the fly ash and bottom ash precludes the potential of using either of the ashes in a utilizational scheme requiring only fly ash or only bottom ash.

DETERMINATION OF QUANTITY

The first six steps of the procedure helped to define the operating system that includes the production, collection, handling, and storage of the coal ash. The following three steps will help approximate the amounts by weight of fly ash and bottom ash that compromise the total amount of ash produced and collected at the heat plant.

Step 7

This calculation determines the total amount of ash produced for the six month period. The percent ash in the coal is from Step 1 and the amount of coal burned from Step 2.

Total ash = coal consumption x % ash content
= 52,161 tons x 7%
= 3,651.27 tons

Step 8

These calculations determine the amount of fly ash produced and collected during the six month period. The figure for total ash is from Step 7 and the percentage of fly ash from Step 3[1].

Total fly ash = total ash x % fly ash
= 3,651.27 tons x 15%
= 547.9 tons

The efficiency of the electrostatic precipitator is from Step 4.

Fly ash collected = total fly ash x overall collector efficiency
= 547.9 tons x 97%
= 531.26 tons

Step 9

This calculation determines the amount of bottom ash produced and collected during the six month period. The figure for total ash is from Step 7 and the percentage of bottom ash from Step 3. The relationship between fly ash and bottom ash is: % bottom ash = 1 - % fly ash.

Bottom ash collected = total ash x % bottom ash
= 3,651.27 tons x 85%
= 3,103.58 tons

DETERMINATION OF QUALITY

Step 10

This step can be divided into two parts: sampling and the

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[1] Figure 3-3 shows the percentage of fly ash and bottom ash to range from 10 to 20 percent and 80 to 90 percent respectively. For the purpose of demonstrating the use of these equations, percentage figures from the mean of each range were selected for the calculations.

analyses for the chemical and physical properties of the ash.

Three sampling points were identified for the coal ash. First, the fly ash from the electrostatic precipitators can be sampled from the fly ash hoppers located in a small room below the precipitators. The techniques for sampling from bulk storage would be appropriate for sampling at this point in the heat plant. Second, the bottom ash can be sampled from the bottom ash hopper located on the lower level directly below the furnace. The bottom ash must be raked out of the hopper because it has a flat bottom. Techniques for sampling from bulk storage may also be used at this sampling point. However, the individual taking the sample must be careful to rake the bottom ash from as much of the flat surface area of the hopper as possible. This will allow for a more representative sample of the bottom ash. Third, the mixed fly ash and bottom ash can be sampled from the storage silo where the two types of ash are mixed. The sampling point is the discharge chute at the bottom of the silo. There is one problem with this sampling point. The fly ash and bottom ash hoppers are not always emptied into the silo at the same time. Therefore, it is possible to have segregated layers of fly ash and bottom ash in the silo. As a result, the ratio of fly ash and bottom ash in the mixture may not be constant from one sample to the next. The individual taking the sample must closely monitor the ash as it falls into the sampling device; any noticeable change in the appearance of the ash stream will signal that the sample is not representative of the actual fly ash-bottom ash mixture.

The second part of this step would be to conduct chemical and physical analyses of the ash samples. This was not accomplished for the reason stated in the introduction to this chapter. However, a discussion of two possible courses of action an engineer may take for determining the quality of the ash and identifying potential users is provided.

The first course of action is to use a standard package of tests to define the quality of the ash. A review of the discussion from Chapter II about the utilization of coal ash will reveal that the activities which encompass the greatest percentage of ash utilization are concrete, concrete products, and road construction. Therefore, in order to make the standard package of tests applicable to the largest percentage of potential ash users, tests for the utilization areas mentioned above should be included in the package. The standard package would include the following ASTM specifications from Appendix C:

- C 618
- C 595
- C 330
- C 331
- C 332
- D 1241

The titles for these ASTM specifications can be found in Appendix C.

The cost of this standard package of tests is approximately $450. Laboratory testing costs may vary for different locations. If the engineer is aware of an actual ash utilization in the local area, it would be feasible to add a test specification for the particular utilization to the standard package.

The tests from the standard package will define the quality of the coal ash and the calculations from Steps 7 through 9 will determine the amount of coal ash available. With a knowledge of the quality and quantity of the ash product, as defined by the specifications in the standard package, the engineer will know what type of ash product the base has to offer potential ash users. The engineer may then consult with the Defense Property Disposal Office (DPDO). The DPDO has the resources available to advertise and sell the coal ash.

The second course of action that may be employed is to conduct a preliminary survey of potential ash markets in the local area before conducting an indepth analysis of the coal ash samples. The major activities of the market survey would include (14:p. 15-15):

- Identifying potential markets for the coal ash.
- Investigating markets to evaluate utilization potential. In particular, conditions of supply and demand and quality requirements should be considered.
- Ranking markets based on relevant characteristics (e.g., demand potential, long-term stability, and distance from heat plant).
- Evaluating any technological changes required to produce

the ash in a utilizable form.

. Selecting the most feasible markets for the coal ash.

The results of the market survey will identify the most feasible markets for potential ash users. With this information it will be possible to select specific ASTM specifications for defining the quality of the ash for each potential ash utilization identified by the market survey. This course of action is more precise than the standard package mentioned previously. It identifies both the potential market and the tests to be used for the coal ash analysis. However, it is both more costly and time consuming. The market survey should be contracted to an ash marketing company that is familiar with the procedures and requirements for ash marketing. Appendix D contains an information source for ash marketing companies.

Even though the economic factors concerning the marketing and sale of coal ash are outside the scope of this research effort, the engineer should be aware of how they can affect the potential for actual ash utilization. After identification of the most feasible markets for the coal ash, an economic evaluation of utilization strategies, including disposal, would be performed. This evaluation would include consideration of the revenue from coal ash sales, comparative transportation costs, and the extended useful life of the disposal site for the coal ash that is not utilized.

In the final analysis, for the recycling of coal ash to be viable, the market must be sufficiently stable to allow amortizing any additional costs of producing the utilizable coal ash over a reasonable projected life. Furthermore, the total cost (capital and operational) of producing the utilizable coal ash should be offset by the anticipated revenues and by the extended life of the coal ash disposal site.

SUMMARY

This chapter provided an example of how the procedure presented in Chapter IV is used by conducting a test case for a heat plant at Wright-Patterson AFB, Ohio. The procedure was validated up to the point before actual sampling and analysis of the ash. Conducting the test case verified that the data required for the procedure was available from the information sources identified in each step of the procedure. Two courses of action that could be employed to select test procedures and identify potential ash markets were discussed.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This final chapter brings together the efforts of the thesis research. A brief summary of each chapter is provided. Conclusions drawn from the research are discussed and, lastly, recommendations from the total thesis effort are given. Areas for further research are also recommended.

SUMMARY

Chapter I provided the problem statement and research objectives to be achieved by this thesis effort. The chapter overview explained the problems experienced with the management and utilization of coal ash in the civilian sector of the U.S. economy. An overview of DOD and Air Force plans to obtain a greater percentage of their energy needs through the increased utilization of coal revealed a potential to encounter ash management problems similar to those experienced in the civilian sector. The scope of the research and research methodology were also addressed.

Chapter II provided the background and technical information for the development of the model. Coal ash was defined as the by-product of the combustion process in coal-fired utility and industrial boilers. Systems for the production, collection, handling, and storage of coal ash were discussed. How different variations of these systems affect the chemical and physical properties of the ash was explained. The chapter concluded with a review of the many resource utilizations that have been developed for the use of coal ash.

Chapter III addressed research objective number one. The purpose of this research objective was to develop a model that will enable identification of the factors which affect the utilization potential of coal ash. The term resource utilization potential was defined as the possibility for a coal ash to be used as a material resource as defined by the material standards that pertain to a particular coal ash utilization. Factors affecting the resource utilization potential of the coal ash were identified and defined as a function of the systems used for the production, collection, handling, and storage of ash. The research method was to start with a definition of the term resource utilization potential and work backward to identify and define the factors that affect the final factor in the model. The final factor being the resource utilization potential of the coal ash.

Chapter IV addressed research objective number two. The purpose of this research objective was to develop a procedure to analyze the portions of the model that will aid a base engineer in determining the utilization potential of the coal ash. A ten step procedure was developed to measure the factors that affect the resource utilization potential of the coal ash. The first six steps of the procedure define the system for production, collection, handling, and storage of the coal ash. The next three steps determine the quantity of ash produced and collected. The last step of the procedure involves determining the quality of the ash. The research method was to measure and sequence the factors identified in the model in a manner that would lead to a determination of the resource utilization potential of the coal ash.

Chapter V presented a test case of the procedure. The purpose of the test case was to provide an example of how the procedure is used and to validate that the data required for the procedure was available from the sources of information identified in the procedure. The test case also verified the sequence of the steps in the procedure. Since an actual analysis of ash samples was not accomplished and actual utilization not demonstrated, two possible courses of action that could be employed to select test procedures and identify potential markets were discussed.

CONCLUSIONS

It was concluded that the plan for increased utilization of coal as an energy source at U.S. Air Force installations has the potential to create ash disposal problems for the Air Force. It was also concluded that the potential exists to lessen the impact of the ash disposal problem through utilization of the coal ash as a recoverable resource.

Air Force engineers need an evaluation tool that will aid them in determining whether or not the coal ash produced at present Air Force coal burning installations has a utilization potential. The evaluation tool should also provide an insight to the design alternatives for the selection of conversion strategies at installations scheduled for conversion to coal. The design selected should be one that will enhance the resource utilization potential of the coal ash by-product.

The research objectives of this thesis effort led to the development of a model and procedure for determining the resource utilization potential of a coal ash. The use of this procedure and a knowledge of the information presented in this thesis will aid an engineer in determining the resource utilization potential of a coal ash.

The ability to utilize the coal ash from Air Force installations as a resource has the potential to lessen the impact of the disposal problem for coal ash at Air Force installations.

RECOMMENDATIONS

Recommendations for Management Action

One of the primary recommendations of this thesis effort is that Air Force engineers responsible for environment evaluations of coal-fired heat plants be made aware of the many possibilities for the utilization of coal ash. An attitude must be engendered that identifies coal ash not only as a disposal problem but also an opportunity to enhance resource and energy conservation and reduce environmental damage through the utilization of coal ash as an alternate resource.

More consideration should also be given to the design of the ash production, collection, handling, and storage systems used in heat plants being converted to coal. The utilization potential of the ash can be enhanced by using dry-methods for the collection, handling, and storage of the ash.

Where applicable, the use of coal ash as an alternate construction material should be included in Air Force construction contracts. An example would be the use of fly ash in the concrete for foundations, roads, or runways. Making contractors aware of the utilization possibilities of coal ash will eventually increase the overall utilization percentage of coal ash produced in the United States. An increasing awareness of the potential of coal ash as a resource may result in an increased demand for this by-product. Increased demand would create markets for coal ash from Air Force installations and reduce the disposal problem.

Recommendations for Future Study

A logical next step for future study is the development of a market survey similar to the one discussed in Chapter V. The survey could be used to define the local market area for the heat plant and provide a method for selecting the most feasible markets for the coal ash. Knowledge of the most feasible markets would help determine what type of tests to request for the analysis of the ash. The requirements for each market could then be evaluated against the results of the ash analyses. Plans for actual utilization of the ash could then be formulated.

A next step in a sequence for future study would involve using both the procedure developed in this thesis and the market survey instrument (yet to be developed) at each coal-burning Air Force base to determine what potential markets are available to the Air Force for the marketing of coal ash. A survey of all coal-burning bases would allow the identification of possible regional markets that more than one base may be able to use. If the utilization potential of the coal ash at a base was diminished due only to not being able to satisfy the quantity demanded by the market, it may be possible to identify another base in the market region that satisfies the quality standards of the market. The two bases together may then be able to satisfy the quantity demand of the market and realize an actual utilization of the coal ash from both bases.

APPENDICES

APPENDIX A

TECHNICAL TERMS, ACRONYMS, AND CONCEPTS

AASHO: American Association of State Highway Officials

Admixture: A material other than water, aggregates, and hydraulic cement used as an ingredient of concrete or mortar and added to the batch immediately before or during its mixing [6:78].

Aggregate: A granular material of mineral composition such as sand, gravel, shell, slag, or crushed stone, used with a cementing medium to form mortars or concrete, or alone as in base courses, railroad ballasts, etc. [6:566].

Anthracite: A hard, black, lustrous coal that burns efficiently and is therefore valued for its heating quality [12:467].

Asphalt: A dark brown to black cementitious material in which the predominating constituents are bitumens which occur in nature or are obtained in petroleum processing [6:564].

ASTM: The American Society for Testing and Materials

ASTM Standards: Those test methods, definitions, recommended practices, classifications, and specifications that have been formally adopted by the Society . . . [6:iii].

Bitumen: A class of black or dark-colored (solid, semisolid, or viscous) cementitious substances, natural or manufactured, composed principally of high molecular weight hydrocarbons, of which asphalts, tars, pitches, and asphaltities are typical [6:564].

Bituminous Coal: Soft coal, coal that is high in carbonaceous and volatile matter. When volatile matter is removed from bituminous coal by heating in the absence of air, the coal becomes coke [12:467].

Blended Cement: A hydraulic cement consisting of an intimate and uniform blend of Portland cement and fine pozzolan produced either by intergrinding Portland-cement clinker and pozzolan, or by blending Portland cement and finely divided pozzolan, or a combination of intergrinding and blending, in which the pozzolan constituent is between 15 and 40 weight percent of the Portland-pozzolan cement (6:346).

Boiler Slag: The ash content collected at the bottom of a wet-bottom type of furnace. The ash consists of angular particles with a glassy appearance (47:248).

Bottom Ash: The ash content collected at the bottom of a dry-bottom type of furnace. The ash consists of angular particles with a porous surface texture (47:248).

Clinker: Generally a fused or partly fused by-product of the combustion of coal, but also including lava and Portland-cement clinker, and partly vitrified slag and brick [6:79].

Coal: A solid, combustible organic material formed by the decomposition of vegetable material without free access to air. Chemically, coal is composed chiefly of condensed aromatic ring structures of high molecular weight. It thus has a higher ratio of carbon to hydrogen content than does petroleum [12:468].

Concrete: The hard, compact substance made by mixing sand, gravel, cement, and water in the proper proportions.

DOD: Department of Defense

Dry-Bottom Furnace: A type of coal burning furnace, formed with a hopper bottom, that has sufficient cooling surface so that the ash collected on the hopper bottom is solid and essentially dry (47:248).

EPA: Environmental Protection Agency

Fly Ash: The fine, solid particles of noncombustible material residual carried from a bed of solid fuel by the gaseous products of combustion [12:470].

Hydration: The chemical reaction between hydraulic cement and water forming new compounds most of which have strengthening properties [5:197].

Hydraulic Cement: A cement that is capable of setting and hardening under water due to the interaction of water and the constituents of the cement [5:197].

Leachate: The liquid that has percolated through or drained from hazardous waste or other man-placed materials from which it removes either soluble, partially soluble, or immiscible compounds [25:p.7-1].

Lignite: A low-grade coal of a variety intermediate between peat and bituminous coal [12:472].

NAA: National Ash Association

NCA: National Coal Association

Particulates: Solid particles, such as the ash, which are released from combustion processes in exhaust gases at fossil-fuel plants [12:475].

Portland Cement: A hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an interground addition [6:105].

Pozzolan: A siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties [6:346].

<u>RCRA</u>: Resource Conservation and Recovery Act

<u>Screen</u>: In laboratory work an apparatus, in which the apertures are circular, for separating sizes of material [6:566].

<u>Sieve</u>: In laboratory work an apparatus, in which the apertures are square, for separating sizes of material [6:566].

<u>Specification</u>: A precise statement of a set of requirements to be satisfied by a material, product, system, or service, indicating whenever appropriate, the procedure by means of which it may be determined whether the requirements given are satisfied [6:iii].

<u>Wet-Bottom Furnace</u>: A type of coal burning furnace in which the ash content that is collected at the bottom of the furnace is maintained in a liquid condition by maintaining a temperature on the ash well above its fusion temperature (47:247).

<u>Workability of Concrete</u>: That property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity [6:79].

APPENDIX B

PRESENT AND PROPOSED AIR FORCE COAL-FIRED INSTALLATIONS

U.S. Air Force bases presently burning coal:

- Chanute AFB IL
- Clear AFB AK
- Eilsen AFB AK
- Grissom AFB IN
- K.I. Sawyer AFB MI
- Loring AFB ME
- Mountain Home AFB ID
- Otis AFB MA
- Rickenbacker AFB OH
- Selfridge AFB MI
- Wright-Patterson AFB OH

U.S. Air Force bases scheduled for conversion to coal-fired central heat plants (1:p.3-4):

FY	Base
79	F.E. Warren AFB WY
81	Fairchild AFB WA
82	Malmstrom AFB MT
82	Arnold Engineering Center TN
82	McClellan AFB CA
83	McGuire AFB NJ
83	Tinker AFB OK
84	Scott AFB IL
84	Kelly AFB TX
84	Seymour-Johnson AFB NC
85	Hill AFB UT
85	Offutt AFB NE

The following bases will be considered in the long-term for the installation of a coal-fired central heating plant (1:p.3-5):

- Lowry AFB CO
- Keesler AFB MS
- Chanute AFB IL
- Eglin AFB FL
- Moody AFB GA
- Hulburt Field FL
- Peterson AFB CO
- Sheppard AFB TX
- Reese AFB TX
- Whiteman AFB MO

The following heating plants with boilers over 50 million Btu per hour currently burning oil will be budgeted for conversion to coal in future years (1:p.3-5):

- Griffis AFB NY
- Plattsburg AFB NY
- Dover AFB DE
- Charleston AFB SC
- Andrews AFB MD

APPENDIX C

ASTM STANDARDS AND SPECIFICATIONS

Once representative samples of the coal ash have been obtained, deciding what chemical and physical tests should be performed to analyze the ash can be a perplexing problem. Testing for specific properties depends upon what utilization is being considered for the ash. If the engineer has in mind a specific utilization for the ash, it can be analyzed against a specification designed for the utilization. Otherwise, an analysis of the properties discussed in Chapter IV may be performed.

To aid the engineer in dealing with this problem, a list of 20 ASTM specifications applicable to the utilization of coal ash are included in this appendix. The specification will apply to a particular utilization, i.e., ASTM D242, "Mineral Filler for Bituminous Paving Mixtures." The specification contains a list of ASTM methods of sampling and testing that will be used by the testing laboratory to analyze the ash for comparison against the standards enumerated in the specification.

The specifications are listed in six categories. The number in parenthesis following the category title identifies the part number from the 1978 Annual Book of ASTM Standards in which the specifications are printed. The part numbers for a different printing of the ASTM Standards may not be the same as those for 1978. However, the category titles will be the same. The specifications marked by an asterisk contain a direct reference to fly ash.

Aggregates (14)

C33	Concrete Aggregates
C144	Aggregates for Masonry Mortar
*C330	Lightweight Aggregates for Structural Concrete
*C331	Lightweight Aggregates for Concrete Masonry Units
*C332	Lightweight Aggregates for Insulating Concrete
C404	Aggregates for Masonry Grout
D1241	Materials for Soil-Aggregate Subbase, Base, and Surface Courses
D2940	Graded Aggregate Material for Bases or Subbases for Highways or Airports

Concrete (14)

*C618	Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete

Cement (14)

*C595	Blended Hydraulic Cements

Highway Construction Materials (15)

*D242	Mineral Filler for Bituminous Paving Mixtures
D692	Coarse Aggregate for Bituminous Paving Mixtures
D693	Crushed Stone, Crushed Slag, and Crushed Gravel for Dry or Water Bound Macadam Base Courses and Bituminous Macadam Base and Surface Courses of Pavements
D1073	Fine Aggregate for Bituminous Paving Mixtures
D1139	Crushed Stone, Crushed Slag, and Gravel for Single or Multiple Bituminous Surface Treatments
D3515	Bituminous Paving Mixtures, Hot-Mixed, Hot-Laid

Waterproofing and Roofing Materials (15)

D1863	Mineral Aggregate Used on Built-Up Roofs

Lime (13)

C35	Inorganic Aggregates for Use in Gypsum Plaster
*C593	Fly Ash and Other Pozzolans for Use with Lime
C737	Limestone for Dusting of Coal Mines

ASTM D242 Standard Specification for "Mineral Filler for Bituminous Paving Mixtures" is reproduced here as an example.

Standard Specification for
MINERAL FILLER FOR BITUMINOUS PAVING MIXTURES[1]

This Standard is issued under the fixed designation D 242; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

$^{\epsilon}$ NOTE—Section 4 was editorially revised in September 1975.

1. Scope

1.1 This specification covers mineral filler added as a separate ingredient for use in *bituminous paving mixtures.*

2. General Description

2.1 Mineral filler shall consist of finely divided mineral matter such as rock dust, slag dust, hydrated lime, hydraulic cement, fly ash, loess, or other suitable mineral matter. At the time of use it shall be sufficiently dry to flow freely and essentially free from agglomerations.

3. Physical Requirements

3.1 Mineral filler shall be graded within the following limits:

Sieve	Percent Passing (by Weight)
No. 30 (600-μm)	100
No. 50 (300-μm)	95 to 100
No. 200 (75-μm)	70 to 100

3.2 The mineral filler shall be free from organic impurities and have a plasticity index not greater than 4.

NOTE—Plasticity index limits are not appropriate for hydraulic lime and cement.

4. Methods of Sampling and Testing

4.1 The mineral filler shall be sampled and the properties enumerated in this specification shall be determined in accordance with the following ASTM methods:

4.1.1 Methods C 50, Sampling, Inspection, Packing, and Marking of Lime and Limestone Products.[2]

4.1.2 Methods C 183, Sampling Hydraulic Cement.[2]

4.1.3 Methods C 311, Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete.[3]

4.1.4 Method D 423, Test for Liquid Limit of Soils.[4]

4.1.5 Method D 424, Test for Plastic Limit and Plasticity Index of Soils.[4]

4.1.6 Method D 546, Sieve Analysis of Mineral Filler for Road and Paving Materials.[5]

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[1] This specification is under the jurisdiction of ASTM Committee D-4 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.50 on Aggregate Specifications.

Current edition effective June 25, 1970. Originally issued 1926. Replaces D 242 - 64.

[2] *Annual Book of ASTM Standards*, Part 13.

[3] *Annual Book of ASTM Standards*, Part 14.

[4] *Annual Book of ASTM Standards*, Part 19.

[5] *Annual Book of ASTM Standards*, Parts 15 and 19.

Note the reference to fly ash in Section 2. Section 3 contains the specifications that the fly ash must satisfy. Section 4 enumerates the methods of sampling and testing. In order to have a resource utilization potential for this particular utilization, the fly ash must satisfy the physical requirements in Section 3 of the specification.

The specifications discussed so far have been applicable to coal ash itself as a raw material. Recall from Chapter III that the specifications that a coal ash must satisfy may be either a test of the coal ash itself or a test of a composite material of which the coal ash is a part. An example of the latter type of specification would be building brick made from fly ash. The following is a partial list of specifications for products that can be manufactured using coal ash as an alternative material:

C7	Paving Brick
C14	Concrete Sewer, Storm Drain, and Culvert Pipe
C55	Concrete Building Brick
C62	Building Brick (Solid Masonry Units Made From Clay or Shale)
C77	Concrete Drain Tile
C90	Hollow Load-Bearing Concrete Masonry Units
C118	Concrete Pipe for Irrigation or Drainage
C129	Non-Load-Bearing Concrete Masonry Units
C145	Solid Load-Bearing Concrete Masonry Units

APPENDIX D

INFORMATION SOURCES

The following organizations are excellent sources of information for coal ash:

- National Ash Association
  1819 H Street NW
  Washington, D.C. 20006
  (202) 659-2303
  Information source for ash marketing companies.

- Electric Power Research Institute
  Research Reports Center
  P.O. Box 50490
  Palo Alto, California 94303
  (415) 965-4081
  Ask for a copy of the EPRI Guide.

- Morgantown Energy Technology Center
  U.S. Department of Energy
  P.O. Box 880
  Morgantown, West Virginia 26505
  (304) 599-7764
  Ask for a copy of the booklet, <u>Publications on Coal, Petroleum and Natural Gas Research.</u>

SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

1. Air Force Engineering and Services Center. Air Force Facility Energy Plan FY 76-85. Tyndall AFB FL. 1 July 1979.

2. ________. Facility Energy Fact Book. Tyndall AFB FL, 1979.

3. ________. U.S. Air Force Energy Management Annual Report. Tyndall AFB FL, June 1980.

4. Allen-Sherman-Hoff Company. A Primer on Ash Handling Systems. Malvern PA, 1976.

5. American Society for Testing and Materials. 1973 Annual Book of ASTM Standards. Part 9, Philadelphia PA, 1973.

6. ________. 1978 Annual Book of ASTM Standards. Part 14, Philadelphia PA, 1978.

7. Brackett, C.E. "Production and Utilization of Ash in the United States," Proceedings: Third International Ash Utilization Symposium. MERC, Morgantown WV, 1973, pp. 12-18.

8. Bradbury, H.W. "The Use and Potential for Fly Ash in Grouting," Proceedings: Fourth International Ash Utilization Symposium. ERDA, St. Louis MO, 1976, pp. 911-929.

9. Callsen, Donald. USAF/LEEEU, Coal Converstion Program, Bolling AFB DC. Telephone Interview. 30 April 1981.

10. Canon, R.M., F.G. Seeley and J.S. Watson. "Engineering Analysis and Comparison of New Processes for the Recovery of Resource Materials from Coal Ash," Proceedings: Fifth International Ash Utilization Symposium. METC, Atlanta GA, 1979, pp. 56-67.

11. Covey, James N. Executive Director, National Ash Association, Washington. Telephone Interview. 23 April 1981.

12. Dorf, Richard C. Energy Resources and Policy. Reading MA: Addison-Wesley Publishing Company, 1978.

13. Electric Power Research Institute. Coal Ash Disposal Manual. EPRI Report FP-1257, Palo Alto CA, December 1979.

14. ________. FGD Sludge Disposal Manual. EPRI Report CS-1515, Palo Alto CA, September 1980.

15. ________. Fly Ash Structural Fill Handbook. EPRI Report EA-1281, Palo Alto CA, December 1979.

16. Faber, John H. "Ash Availability and Uses," Proceedings of the Ash Management Conference. Texas A&M University, College Station TX, 25-27 September 1978, pp. 67-82.

17. ________. "U.S. Overview of Ash Production and Utilization," Proceedings: Fourth International Ash Utilization Symposium. ERDA, St. Louis MO, 1976, pp. 5-13.

18. Faber, J.H. and A.M. DiGioia, Jr. "Use of Ash for Embankment Construction," Proceedings: Transportation Research Board Annual Meeting, January 1976.

19. Francis, Wilfrid. Boiler House & Power Station Chemistry. London: Edward Arnold (Publisher) Ltd., 1955.

20. GAI Consultants, Inc. Guide for the Design and Construction of Cement-Stabilized Fly Ash Pavements. Washington: The National Ash Association, 1976.

21. Gerlich, J.W. "Fly Ash as a Filter Aid," Power Engineering, January 1970, pp. 44-45.

22. Hansen, Penelope. "Government Procurement of Recycled Products--Fly Ash in Cement and Concrete," Proceedings: Fifth International Ash Utilization Symposium. METC, Atlanta GA, 1979, pp. 51-55.

23. Johnson, Carlton. "Flyash Removes SO_2 Effectively from Boiler Flue Gases," Power Engineering, June 1979, pp. 61-63.

24. Liegeois, Paul. Engineer, Industrial Applications Department, Wisconsin Public Service Corp., Green Bay WI. Telephone Interview. 24 December 1980.

25. Los Alamos Scientific Laboratory. Environmental Contamination from Trace Elements in Coal Preparation Wastes. Springfield VA: National Technical Information Service, August 1976. PB 267 339.

26. Marcus, Luciano A. "Ash Economics Vs. Quality," Proceedings of the Ash Management Conference. Texas A&M University, College Station TX, 25-27 September 1978, pp. 92-105.

27. Mather, Bryant. "Portland-Pozzolan Cement Made With Tennessee Valley Authority Fly Ash," Army Engineer Waterways Experimental Station, Vicksburg MS, May 1960. AD 751103.

28. McClean, Emory T. and Murray T. Dougherty. "Hillman State Park: Final Assessment of Fly Ash as a Soil Modifier for Acidic Strip Mine Spoil," Proceedings: Fourth International Ash Utilization Symposium. ERDA, St. Louis MO, 1976, pp. 816-839.

29. Morrison, Ronald E. "Power Plant Ash: A New Mineral Resource," Proceedings: Fourth International Ash Utilization Symposium. ERDA, St. Louis MO, 1976, pp. 200-210.

30. National Ash Association. Ash At Work. Vol. VIII, No. 4. Washington, 1976.

31. ________. Ash At Work. Vol. VIII, No. 5. Washington, 1976.

32. ________. Ash At Work. Vol XIII, No. 1. Washington, 1981.

33. ________. "'Ashphalt' Used On Secondary Roads," Ash At Work Technical Bulletin. No. 10. Washington.

34. ________. "Bottom Ash Backfill Used to Protect Wall," Ash At Work. Vol. XII, No. 1. Washington, 1980.

35. ________. "Bottom Ashes in Road Construction," Ash At Work Technical Bulletin. No. 8. Washington.

36. ________. How Fly Ash Improves Concrete Block, Ready-Mix Concrete, Concrete Pipe. Washington.

37. National Geographic Society. Energy: Facing Up to the Problem, Getting Down to Solutions. A Special Report, Washington, February 1981.

38. Ohanian, M.J. and Faramarz Fardshisheh. "Coal Availability and Coal Mining," in A.E.S. Green, Ed., Coal Burning Issues. Gainesville FL: University Presses of Florida, 1980.

39. Owens, Philip L. "The Development of Fly Ash as a Pozzolan for Economic Concrete," Proceedings: Fourth International Ash Utilization Symposium. ERDA, St. Louis MO, 1976, pp. 542-559.

40. Philleo, Robert E. "Ash Utilization from the Corps of Engineers Viewpoint," Proceedings of the Ash Management Conference. Texas A&M University, College Station TX, 25-27 September 1978, pp. 47-58.

41. Ray, S.S. and F.G. Parker. Characterization of Ash from Coal-Fired Power Plants. Springfield VA: National Technical Information Service, January 1977. EPA-600/7-77-010.

42. Ryan, Christopher R. "Refuse Pile Fire Abatement Using Flyash Injection," Proceedings: Fourth International Ash Utilization Symposium. ERDA, St. Louis MO, 1976, pp. 665-676.

43. Santhanam, Chakra J. and C. Robert Ullrich. "Characterization of Flue Gas Cleaning (FGC) Wastes from Coal Combustion," Proceedings: Fifth International Ash Utilization Symposium. METC, Atlanta GA, 1979, pp. 405-447.

44. Schneider, Richard T. and Michael J. Rowe. "Coal Burning Technology," in A.E.S. Green, Ed., Coal Burning Issues. Gainesville FL: University Presses of Florida, 1980.

45. Seals, R.K., L.K. Moulton, and B.E. Ruth. "Bottom Ash: An Engineering Material," Journal of the Soil Mechanics and Foundations Division, ASCE, April 1972, pp. 311-325.

46. Sloanaker, John F. "The Role of Flyash Brick Manufacturing in Energy Conservation," Proceedings: Fifth International Ash Utilization Symposium. METC, Atlanta GA, 1979, pp. 85-88.

47. Styron, Robert W. "Bottom Ash Lightweight Aggregate," Proceedings: Fifth International Ash Utilization Symposium. METC, Atlanta GA, 1979, pp. 245-253.

48. Tetra Tech, Inc. U.S. Air Force Energy Plan 1978. Arlington VA, 1978.

49. U.S. Department of the Interior. Minerals Yearbook: 1977. Washington: Government Printing Office, 1977.

50. Useman, Mumtaz and David A. Anderson. "Use of Power Plant Aggregate in Asphaltic Concrete," Proceedings: Fourth International Ash Utilization Symposium. ERDA, St. Louis MO, 1976, pp. 151-169.

51. Wark, K. and C.F. Warner. Air Pollution, Its Origin and Control. New York: IEP A Dun-Donnelley, 1976.

52. Wisconsin Public Service Corporation. Fly Ash Idea Kit. Green Bay WI, September 1977.

B. RELATED SOURCES

American Society for Testing and Materials. 1978 Annual Book of ASTM Standards. Part 15, Philadelphia PA, 1978.

________. 1978 Annual Book of ASTM Standards. Part 16, Philadelphia PA, 1978.

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