Chapter 2

BACKGROUND AND CHARACTERIZATION OF COAL REFUSE

Safe, economical and environmentally acceptable disposal of coal refuse has been made possible through the application of technology from the disciplines of geology, soil and rock mechanics, hydrology, hydraulics, geochemistry, soil science, agronomy and environmental sciences. These engineering and scientific disciplines have traditionally supported the design and construction of earthfill and rockfill embankments and dams, as well as a wide variety of waste disposal structures used in other industries. Among the various types of coal refuse disposal facilities, impoundments are one of the most critical types of structures, and they entail many of the same features and safety concerns as typical water-impounding dams. However, there are distinct differences between coal refuse disposal impoundments and conventional dams that must be considered in the transfer of dam engineering technology to coal refuse disposal, as discussed in the following:

- The primary purpose of a coal refuse disposal facility is to dispose of unusable materials from mining, not to construct an embankment to satisfy a secondary function. However, at some sites coal refuse impoundments do serve secondary purposes such as providing water storage capacity for coal processing and flood attenuation.

- Coal refuse is composed of rock fragments such as friable shale materials, and it typically includes varying amounts of coal that can have an effect on material behavior. For example, the low specific gravity of coal results in the refuse having lower specific gravities and densities than the materials encountered in typical earth embankments.

- Metals and sulfur present in some coal refuse materials may result in environmentally undesirable leachate water with serious corrosive characteristics that require special measures such as liner and collection systems or even amendments to neutralize acid production of the refuse.

- The potential for variations in coal refuse production as a result of mining or processing, plus the long-term phased method of refuse placement, should be accounted for in the disposal facility design at inception. The potential for changes in generation rates and engineering properties of the coal refuse during the life of the facility should also be recognized and provisions to accommodate these changes should be included in the design.

- The configuration of a disposal facility changes continually throughout its operational period, resulting in complications relating to control, but providing increased flexibility for planning, design and construction.

- Coal refuse disposal occurs year round, through prolonged inclement weather periods, such that the design and maintenance of the facility has to accommodate construction under adverse weather conditions.

- The construction of a disposal facility over an operational period of many years or even decades introduces the potential for discontinuity in construction oversight, quality control, monitoring, and recognition of performance factors that can affect operation and safety. The design plans should include specifications for oversight, monitoring, and quality control sufficient so that facility construction and operation meets the design intent.

- A primary planning and construction goal for a disposal facility is achievement of a safe and environmentally acceptable condition during use and upon closure and abandonment. Elimination of the impounding capability of a coal refuse disposal facility is an important design issue associated with abandonment unless maintenance of the facility is part of the planned post-mining operation of the site.

2.1   GEOLOGICAL NATURE OF COAL REFUSE

Coal refuse is composed of rock fragments unavoidably removed from the earth during the coal mining process and small amounts of coal not separated during processing. The primary source of these rocks and minerals is normally the formations immediately above and below the coal seam and the sediments within the seam. Surface mine overburden and rock removed to provide shafts, haulageways and other working space for the mining operation may constitute an important percentage of the total refuse material.

The proportion of rock, coal and associated minerals in any disposal facility will depend upon: (1) the geologic formation of the coal stratum, (2) the geochemical properties of the coal and adjacent materials, (3) the geometry of the coal seam, (4) the method used for mining, and (5) the process used to separate the coal from the refuse. A preparation plant may process coal from multiple seams and mining operations, resulting in some variability of the refuse product. Also, a disposal facility may receive refuse from multiple preparation plants.

2.1.1   Origin of Coal

Coal is a sedimentary rock resulting from past accumulation of plant materials in swampy conditions and subsequent metamorphism by pressure and heat to form a hard, rock-like organic material. The diversity of the original plant materials and the degree of metamorphism (coalification) that has affected these materials cause coal to be a non-uniform, combustible substance varying in both physical and chemical composition.

The predominant elements in coal are carbon, hydrogen and oxygen. Coals are rich in carbon and are classified based primarily as to the content of volatile matter. Table 2.1 presents the American Society for Testing and Materials (ASTM) system for classification of coals by rank. For the anthracite and low- and medium-volatile bituminous coals, the carbon content exceeds about 70 percent. When the volatile matter exceeds about 30 percent, it becomes difficult to classify coals on the basis of volatile matter alone, and caloric value is used to distinguish high-volatile-bituminous, subbituminous, and lignite coals.

Impurities present in coal include nitrogen, sulfur, iron and various other inorganic materials (ash). These impurities can be divided into the following classes: (1) impurities that are chemically or struc-

turally a part of the coal and (2) impurities that can be mechanically removed from the coal. The amount and type of impurities that cannot be economically separated from a particular coal vary greatly and affect value. The impurities that are separable affect the refuse characteristics from a geo-chemical and physical standpoint. These characteristics contribute to the engineering properties of coal refuse and are thus critical to the engineering and design of disposal facilities.

TABLE 2.1 CLASSIFICATION OF COALS BY RANK

Group	Fixed Carbon Limits[1] (%)	Volatile Matter Limits[1] (%)	Calorific Value Limits[2] (BTU/lb)
Anthracite			
Meta-anthracite	≥ 98	< 2	–
Anthracite	92 to 98	2 to 8	–
Semianthracite	86 to 92	8 to 14	–
Bituminous			
Low-volatility bituminous coal	78 to 86	14 to 22	–
Medium-volatility bituminous coal	69 to 78	22 to 31	–
High-volatility-A bituminous coal	< 69	≥ 31	≥ 14,000
High-volatility-B bituminous coal	–	–	13,000 to 14,000
High-volatility-C bituminous coal	–	–	10,500 to 13,000
Subbituminous			
Subbituminous-A coal	–	–	10,500 to 11,500
Subbituminous-B coal	–	–	9,500 to 10,500
Subbituminous-C coal	–	–	8,300 to 9,500
Lignite			
Lignite A	–	–	6,300 to 8,300
Lignite B	–	–	< 6,300

Note: 1. Dry mineral-matter-free basis.
       2. Moist mineral-matter-free basis.

(ADAPTED FROM ASTM, 2008a)

Sulfur, an impurity of major importance, occurs in three principal forms: (1) organic sulfur, (2) sulfate sulfur, and (3) pyritic sulfur. Generally, pyritic sulfur (FeS_2) is the predominant form. Pyrites are of significance in the design of coal refuse disposal facilities because, when exposed to air and water, they oxidize to create acidic conditions that adversely affect the weathering resistance of certain rocks, cause negative environmental impacts, and cause corrosion of some construction materials.

2.1.2   Coal-Related Rocks

The rock formations immediately above and below a coal seam represent a large portion of the material in coal refuse. The character of this rock varies from seam to seam and with the geographic location of an individual coal seam, depending upon the geologic conditions preceding and following the deposition of the coal-forming materials.

Inorganic sedimentary rocks, such as claystone, siltstone, shale, sandstone and occasionally limestone, compose the bulk of the strata where coal is found. These sediments are frequently found in

the coal as inorganic debris deposited during the formation of the organic layer. The most abundant minerals contained in these inorganic rocks are quartz, feldspar, mica (usually muscovite with minor chlorite) and calcite. However, numerous minor components may also be present, and these can vary greatly from site to site. The following sedimentary rocks are listed in an order of decreasing resistance to weathering:

Limestone   A relatively hard, dense rock consisting largely of calcite ($CaCO_3$). This rock is very durable in the weathering cycle, except in the presence of acid (including acid conditions that result from pyritic sulfur), which will dissolve it.

Sandstone   A rock composed of relatively coarse particles cemented together by calcite, silica (SiO_2) argillaceous material or, less commonly, iron. Its strength and resistance to weathering depend upon the cementing agent.

Siltstone   A rock quite similar to sandstone, except for the generally smaller grain size and substantial amount of clay present. The clay portion is subject to rapid weathering, and high clay content can cause rapid deterioration.

Claystone   A rock composed predominantly of clay-sized particles. It may be massive (mudstone) or fissile (shale) in appearance, but in either case, it has a low resistance to weathering

Iron and sulfur impurities are also common in many coal-bearing sedimentary rocks. As with the coal itself, the most significant of these impurities are the pyrites.

2.2   COAL MINING AND COAL PREPARATION (CLEANING)

Coal is mined in more than 400 coal fields and small deposits in 38 states, split between the Eastern (Appalachian and Interior) and Western regions. In the Eastern region, the quality of raw coal has declined as higher quality reserves have been depleted, requiring more cleaning to meet product requirements. The thicker Western region coal seams typically contain fewer in-seam and out-of-seam rock, and much of that coal is shipped raw without extensive processing (NRC, 2002). Accordingly, coal cleaning and the generation of coal refuse is a significant part of mining projects in the Eastern region, which is where most coal refuse impoundments are operated.

In general, the removal of extraneous materials with the coal during the mining process is controlled by three primary factors: (1) the general geology of the mining area and to a greater extent the immediate type and quality of the floor, partings and roof materials, (2) the thickness of the seam to be mined, and (3) the type of mining equipment selected to remove the coal. For example, in longwall mining where a shearer or cutting head is drawn across the face of a coal seam, a constant thickness of material is removed and will contain roof or floor rock in areas of decreased coal seam thickness. This extraneous material, often referred to as "out of seam dilution," is a major source of coal refuse, particularly in the coarser (> 19-mm) size fractions.

Coal preparation (cleaning) removes refuse from the coal. The preparation technique affects the refuse disposal primarily in three ways: (1) the proportion of coal in the refuse (efficiency of the cleaning process), (2) the gradation of the refuse particles, and (3) the moisture content of the refuse as it leaves the preparation plant. Additionally, the use of flocculants and other chemical additives can also affect the composition of refuse materials. Most modern coal preparation plants today recover coal down to 100-mesh (150-micron) size, and some have incorporated cleaning all of the raw coal. Usually a preparation plant will have either two or three circuits (possibly four if the preparation plant cleans all the way to zero impurities) that handle the distinct size fractions discussed in the following paragraphs.

Often raw coal is processed through a scalping screen or rotary breaker ahead of the preparation plant. This is done to control the maximum size of the raw coal arriving at the preparation plant.

Historically, screening has been done at the 4- to 6-inch size range (100- to 150-mm). Recently, however, the trend has been to reduce the separation size down to as small as 1½ inch (37 mm). This has been done to accommodate the use of the simpler two-circuit coal preparation plant. Depending on the mining method and coal characteristics, the rejected material that must be handled at the refuse disposal site can represent 5 to 15 percent of the raw coal.

Typically, coal preparation plants size raw coal into discrete fractions that are processed separately using various types of process technologies. Currently, heavy media technology is typically used for processing raw coal down to 1 mm. Heavy media vessels (down to 9 mm) or heavy media cyclones (down to 1 mm) or a combination of these two technologies are used to process the plus 1-mm raw coal. The heavy media process involves adding magnetite to water to create slurry with a specific gravity that improves the separation efficiency of the process. The magnetite slurry creates a suspension with specific gravity high enough that the coal floats and the refuse materials with higher specific gravity sink. These types of processes are the most efficient and produce a refuse stream with minimal coal. After the separation of the coal from the refuse, the materials are drained and rinsed of the magnetite media on a vibrating screen. Rinse water is added to the vibrating screen to improve the efficiency of the magnetite removal. Typically, the refuse material discharging from the end of the vibrating screen after being rinsed will have a surface moisture in the range of 8 to 15 percent depending upon the minimum size of the refuse being processed.

The 1-mm by 100-mesh (150-micron) size fraction is typically processed using water-only technologies. Technologies used to process this size range include water-only cyclones, spirals, and hindered-bed settlers. After processing, the refuse materials are typically dewatered using a high frequency dewatering screen designed to retain the plus 100-mesh material. The installation of this type of screen ahead of the thickener can significantly reduce the amount of plus 200-mesh particles in the refuse slurry.

If coal cleaning below 100-mesh size is performed, then typically the differences between the surface chemistry of the coal and refuse are exploited to perform a separation (e.g., froth flotation). Froth flotation requires the addition of a collector (typically fuel oil) and a frother (typically glycol or methylisobutyl carbinol (MIBC)) to the slurry. The fine coal particles are hydrophobic and collect on the surface of the air bubbles created by the flotation machine and rise up through the slurry and are removed with the froth. Alternatives to flotation include high gravity concentrators and fine coal spirals used to process the 100-mesh by 325-mesh (44-micron) size fraction.

Due to the high volume of water used in the processing of coal, thickeners are typically used to reclaim the wash water for recirculation. Generally, the use of flocculants is sufficient to remove the majority of coal fines, but when there are high levels of clay in the mined coal, it may be necessary to also add coagulants. The sequential addition of flocculants and coagulants aids in controlling the turbidity of recycled process water and settling of solids that are pumped to the impoundment.

Technologies for dewatering of the thickener underflow include belt filter presses, vacuum filters, plate and frame filters, solid bowl centrifuges, horizontal belt filters, and paste thickeners. When fines are dewatered, the most commonly used technology is the belt filter press. The dewatered product from these technologies typically has moisture contents in the range of 35 to 45 percent. The amount of minus 325-mesh solids in the feed to these unit operations dictates the final moisture of the product. The higher the amount of minus 325-mesh particles in the feed (which is controlled by the geology and mining method), the more difficult it is for the system to operate and to produce a product with manageable moisture.

If fine refuse dewatering is included in the process, refuse streams must be handled either individually or as a combined product. Amendments may be required for pH control or to aid in the handling

of the refuse products. Depending on the amount of fine refuse and its moisture content, the disposal of the combined product may be difficult.

Prior to 1970, many preparation plants did not attempt to separate coal and impurities in the fine-washed material, resulting in a fine refuse with high coal content. This practice resulted in a relatively high ratio of fine refuse volume to coarse refuse volume, and these disposal sites are of interest for remining and recovery of the coal. In general, modern coal preparation plants are more efficient (i.e., lower coal losses to refuse). In addition, the amount of out-of-seam dilution has increased, resulting in higher coarse to fine ratios. This is particularly true in areas where the coal reserve is being depleted. As coal preparation techniques have advanced, the amount of fine coal deposited with the fine refuse slurry has decreased, thus increasing the amount of coarse refuse disposed in relation to the amount of fine refuse.

2.3 REFUSE TRANSPORT AND DISPOSAL PLACEMENT

2.3.1 Coarse Refuse

The method of transporting coarse coal refuse from the preparation plant to the disposal facility is determined by: (1) material gradation, (2) production rate, (3) the distance and topography of the route to the disposal facility and (4) the size, type and configuration of the disposal facility. Although refuse transport methods vary widely, the most common method for transporting coarse refuse is by trucks or scrapers for relatively short distances over moderate terrain, by conveyors for long distances over moderate to steep terrain, or by a combination of these methods. The ramifications of these transport methods on the disposal facilities are further described in Chapter 11.

The placement of coarse refuse at a disposal facility depends upon the method of transport to the disposal facility and the facility configuration. Prior to 1970, coarse refuse transported by truck was generally end-dumped from the truck and allowed to form a progressing embankment at the angle of repose of the material. Another method from that era was to transfer the coarse refuse from a conveyor or continuous bucket tram to an aerial tram that dumped the refuse from a high elevation along a fixed axis, allowing the refuse to form a progressing embankment at the angle of repose of the material except as modified by dozers or scrapers.

Current practice typically includes the use of conveyor systems and/or trucks. Trucks dump the refuse in piles on the disposal surface with subsequent spreading by dozers. If the refuse is transported by conveyor, it is normally dumped into a hopper bin and transferred to trucks or scrapers for placement, as described above. There has been some use of mobile conveyors to deposit coarse refuse directly on the embankment surface for spreading by dozers. The common configurations of coal refuse embankments are described in Chapter 3.

2.3.2 Fine Refuse and Combined Refuse

A common method of transporting fine refuse material has been as slurry pumped to a disposal pond for settling of the solids and clarification of the remaining water. Use of thickeners with the application of flocculants, and in some cases coagulants, improves clarification and settling of solids and facilitates deposition within a slurry impoundment. These additives typically overcome the use of reagents used in the separation and concentration processes of coal preparation.

Another method for transporting fine refuse involves partially dewatering the slurry at the preparation plant. The resulting material is then disposed separately or mixed and placed with the coarse refuse material as combined refuse. There have been many problems associated with transporting and placing the combined material due to the relatively high moisture content of the dewatered fine refuse. Consideration has recently been given to transporting the fine refuse as a paste (thickened

tailings) that can be pumped to a disposal location. The objective in using thickened tailings is to minimize the use of water, generally because of limited availability.

2.4 COAL REFUSE CHARACTERIZATION

Coal refuse is composed of rock fragments, sand, silt and clay particles and contains small amounts of coal not separated during processing.

2.4.1 General Geochemical Characteristics

Coal refuse geochemical characteristics result from the depositional environment of the coal and adjacent strata, the mining and coal preparation process, and the weathering process when the refuse is exposed to air. Coal refuse shares many properties with the coal seam where it originated, with sulfur usually representing the most significant environmental concern. Mining processes may take mine roof and floor materials that contain significant pyrite materials, further affecting sulfur content. Processing of the coal includes crushing, separation, and in some plants recombining coarse and fine refuse. The efficiency of the processing plant at removing sulfur and the degree to which the sulfide fragments are fractured and reduced in size influences the reactivity of the final refuse product. Reagents and additives such as surfactants, oils, and strong bases are used in various separation processes.

Most of the environmental problems associated with coal refuse result from the oxidation of pyrite and subsequent production of acidity. The exposure of coal refuse to weather (air and moisture) enhances the production of acid, leading to a condition of low pH. The pH of a refuse deposit may depend not only on the pyrite content, but also on the length of exposure time and the acid-neutralizing capacity of the refuse. The majority of the coal refuse in the Appalachian region of the U.S. contains an excess of oxidizable sulfur compared to neutralizing carbonates and is therefore net acid producing over time. During the oxidation process, metals are released into soluble forms, resulting in impacts to water quality from drainage through or off the surface of refuse deposits and accumulation of phytotoxic concentrations of acid-soluble metal ions and sulfate salts on refuse surfaces that inhibit the establishment of vegetation during reclamation of the disposal site (Daniels and Stewart, 1993). Western coal regions in the U.S. tend to be less acid producing, but may still pose environmental concerns.

Variability may be found in coal refuse within the same disposal area because: (1) the coal preparation plant may process coal from multiple seams, (2) the process may change over time, and (3) the rate of processing (and thus accumulation and successive covering of earlier refuse deposits) may change due to production and mining factors. The management of refuse at the disposal site can affect the weathering process, with the result that geochemical characteristics can change over relatively short periods of time.

The geochemical characteristics of coal refuse are important planning considerations for coal refuse disposal facilities and can be addressed in a variety of ways. Amendments (additives with neutralization characteristics such as lime products) may be added to provide additional acid-neutralizing capacity that can affect the physical properties of the deposit. Liners (natural soil or synthetic) may be employed for control of seepage from the refuse disposal area and thus will affect foundation requirements and facility configuration.

### 2.4.2 General Geotechnical Characteristics

Each type of coal refuse has characteristic geotechnical properties. Coarse refuse from the preparation process represents a substantial portion of and sometimes the entire waste stream. Where mechanical crushers are included in the coal preparation process, large-diameter rock (on the order of 6 inches in size and referred to as "breaker rock") may also be generated, although it typically represents a small fraction of the refuse materials.

Fine refuse is a separate waste stream resulting from the wet processing of coal. It may be: (1) disposed as a slurry (fine coal refuse slurry) separate from the coarse refuse, (2) dewatered and disposed with the coarse refuse as combined refuse, or (3) dewatered and disposed separately from the coarse refuse (dewatered fine coal refuse or filter cake). An additional form of refuse, although not common, is the slurrying of both coarse and fine refuse (coarse and fine refuse slurry).

Most slurry disposal operations use slurry pumps to transport fine coal refuse at between 5 and 20 percent solids. Thickened tailings are increasingly being considered for fine coal refuse disposal. This practice involves processing the fine coal refuse into a non-settling and non-segregating suspension of solids taking the form of a paste with about 50 percent solids.

2.4.2.1   Coarse Coal Refuse

Coarse coal refuse is typically a well-graded material with particle sizes ranging up to 3 inches and a fines content (as measured by the amount passing the No. 200 sieve or 0.075 mm) ranging from less than 10 percent to more than 20 percent. It is generally classified as a silty, clayey sand with gravel to a clayey, silty gravel with sand. Coarse coal refuse typically has a specific gravity ranging from 1.8 to 2.3, which is lower than many natural soils and aggregates due to the carbon content. Run-of-plant coarse coal refuse generally has a water content of between 8 and 15 percent and loses moisture during transport to the disposal site. As a result, it can readily be compacted to form dense fill in embankments. Figure 2.1 provides the range of grain-size distributions usually encountered for coarse coal refuse at disposal sites and a photograph of a coarse refuse embankment.
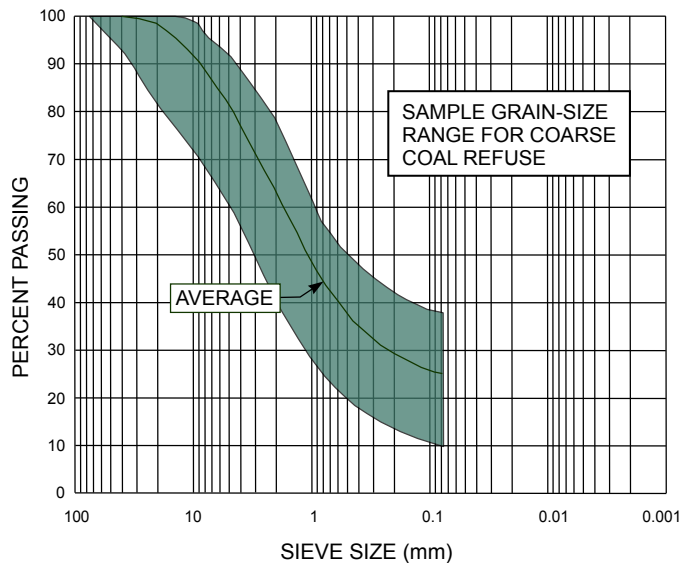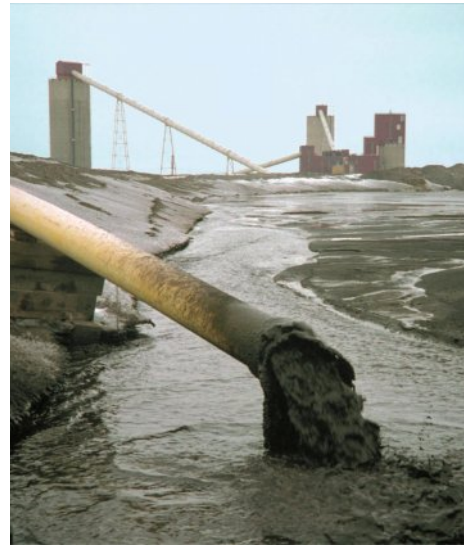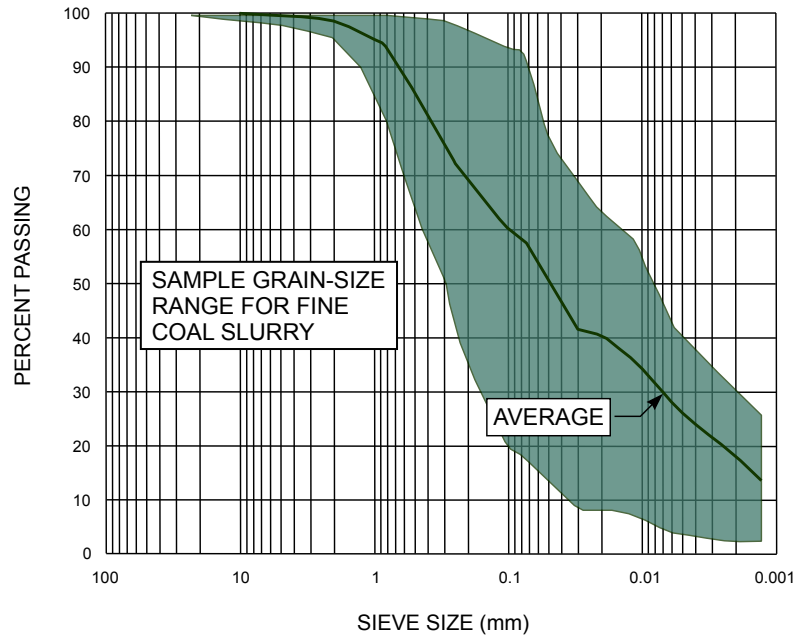

(HEGAZY ET AL., 2004)

FIGURE 2.1 COARSE COAL REFUSE EMBANKMENT AND SAMPLE GRADATION

Coarse coal refuse typically exhibits weathering and some physical degradation during placement and compaction. Thus, the resulting percentage of fines in compacted, weathered coarse coal refuse can be greater than in fresh or recently placed material. Sieve analyses performed on fresh samples before and after compaction have exhibited an average increase in fines content of approximately 4 percent in one northern Appalachian mine. Coarse coal refuse generally has strength, settlement and hydraulic conductivity properties reflective of a well-graded soil and rock fill. Further characterization of coarse refuse is discussed in Chapter 6.

2.4.2.2   Fine Coal Refuse Slurry

Fine coal refuse slurry, when discharged into an impoundment, meanders across previous deposits and the sand-size material commences settling in shallow water. As the slurry discharge velocity

slows and deeper water conditions are encountered, settling of the finer materials occurs, resulting in greater variability in grain size than encountered with other forms of coal refuse placement. Samples collected from or close to the slurry discharge point are predominantly sand- and silt-size material, whereas samples collected away from the discharge point are predominantly silt- and clay-size material. Because the discharge location is typically shifted periodically, there is variability in the grain size of fine refuse materials with elevation as well as location. Figure 2.2 illustrates typical grain-size distributions encountered with discharge of fine coal refuse slurry at impoundments.

(HEGAZY ET AL., 2004)

FIGURE 2.2 FINE COAL REFUSE SLURRY CHARACTERISTICS

Fine coal refuse consists of particles that are mostly less than 1 millimeter in size and frequently has a fines content (as measured by the amount passing the No. 200 sieve) of typically between 30 and 80 percent. The specific gravity of fine coal refuse tends to be lower than that of coarse refuse, typically in the range of 1.4 to 2.0, depending on the percentage of coal fines. Water content will vary significantly dependent upon the grain-size distribution and location within the impoundment. Settled fine coal refuse slurry has strength, settlement and hydraulic conductivity properties reflective of hydraulically-placed deposits of sand, silt and clay, as further discussed in Chapter 6.

2.4.2.3   Dewatered Fine Coal Refuse

Dewatering of fine coal refuse results in a filter cake material with less variability in grain size than observed in hydraulically-placed fine refuse slurry. While the grain-size distribution is relatively consistent for a given coal seam and processing plant, there is typically variation between samples from different coals and processing systems. Filter cake may have a retained water content in excess of 30 percent, and considering the significant amount of silt and clay fraction in the material, frequently cannot be placed and compacted into an embankment without further drying and/or the addition of other materials such as coarse refuse or amendments for moisture control and stabilization. Consequently, dewatered fine coal refuse is generally disposed with coarse refuse either intermixed as combined refuse or segregated to form containment cells.

2.4.2.4   Combined Coal Refuse

Combined coal refuse is a mixture of coarse and fine coal refuse, and thus has a greater fines content and water content than coarse coal refuse. While still well graded, combined refuse may have fines

content in the range of 20 to 40 percent, and water content between 12 and 30 percent. When the fines and/or water content are relatively high, combined refuse may be difficult to compact into a dense embankment and may also be sensitive to inclement weather impacts. Figure 2.3 presents a photograph of combined coal refuse and an illustration of a typical grain-size distribution for combined refuse with a moisture content of 30 percent.
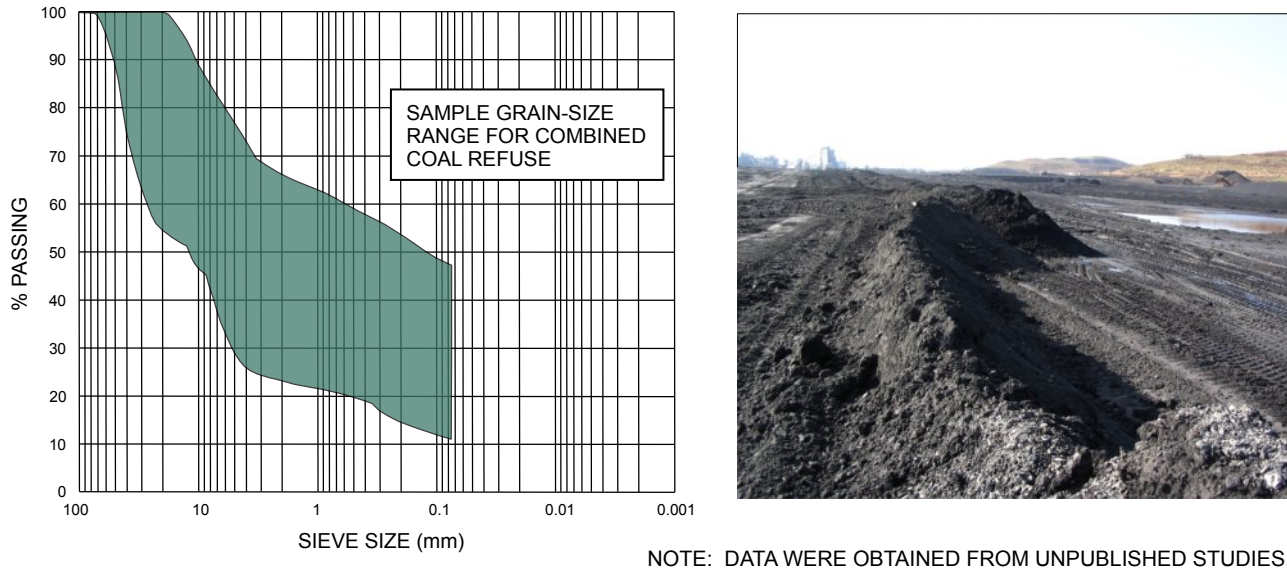

NOTE: DATA WERE OBTAINED FROM UNPUBLISHED STUDIES.

FIGURE 2.3 COMBINED COAL REFUSE MATERIALS

2.4.2.5   Fine Coal Refuse Paste

To reduce the quantity of water associated with fine refuse disposal, thickened tailings technology is currently under study. It is anticipated that the resulting paste will have properties similar to dewatered fine coal refuse from filter presses, but with greater water content. The attraction to this technology lies in certain perceived advantages over filter press operating requirements and the ability to transport the resulting paste by pumping, using less water than required for slurry impoundments. Placement and containment issues are anticipated to be similar to those encountered with disposal of dewatered filter cake. The use of thickened tailings has been implemented at two existing impoundments in the United States (Henry, 2007; Gupta et al., 2008), achieving a paste solids content of 45 to 55 percent that reportedly builds or "stacks" without separation as the paste is deposited.

2.5   DISPOSAL PRACTICES

2.5.1   Disposal Practices Prior to the Buffalo Creek Failure

In February 1972, a coal refuse disposal facility located on a tributary to Buffalo Creek in southern West Virginia failed after several days of rainfall, sending flood water and refuse material through the narrow downstream valley. A number of coal mining communities were devastated, and 125 people were killed. This monumental failure, known as the Buffalo Creek failure, brought the potential danger of similar disposal facilities to the attention of the nation. A summary description of this failure along with other incidents reported at coal refuse disposal facilities is provided in Table 2.2.

Prior to the Buffalo Creek failure, minimal technical effort was devoted to the planning and design of coal refuse disposal facilities in the U.S. Geotechnical and hydraulic characteristics of refuse materials and disposal facilities were seldom considered. Instead, disposal facilities were often developed at

sites chosen for expediency and were often operated with equipment selected by availability rather than suitability for site materials. Most research devoted to coal refuse disposal in the U.S. before 1972 was related to: (1) the prevention of refuse embankment burning, (2) the extinguishment of embankment burning, and (3) the development of vegetation on refuse materials through refuse conditioning and seeding.

Prior to 1972, little or no planning or design was devoted to the control of water entering an impoundment from a preparation plant or from watershed runoff upstream of the disposal facility. Experience had suggested that excess preparation plant water could be clarified naturally by settlement at the impoundment and filtration through the refuse embankment. In most coal refuse impoundments, the water level above the settled slurry reached an equilibrium condition at a depth of less than 10 to 15 feet, at which time the outflow of water from seepage equaled the inflow to the impoundment. This effect, plus the large volume of coarse refuse often placed in the embankment, generally resulted in the maintenance of a large freeboard between the normal water surface and the embankment crest that provided storage for runoff from moderate storms.

The potential risk of coal refuse disposal facilities is related to the storage of water and waste that may be flowable and that, if released, may result in downstream inundation with substantial public safety, economic and environmental consequences. A major reason for emphasizing the potential hazard of disposal facilities with impoundments, as compared to disposal facilities without impoundments, is the large geographical area that may be affected by the rapid release of large volumes of water or waste following embankment failure. Unless a non-impounding embankment is located directly above a populated area such as the disastrous failure in Aberfan, Wales in 1966 (Bignell et al., 1977), or adjacent to a stream where materials movement could block flow, the slippage of such an embankment will cause only localized problems related more to environmental and aesthetic considerations than to public safety. However, embankment failure allowing the rapid release of large volumes of water may cause flooding that is costly not only in terms of miner and public safety, and property and environmental damage, but also in terms of extensive cleanup of the dispersed wet refuse for many miles downstream. In mountainous mining areas complementary industrial, commercial and residential developments are usually located in the downstream valley bottom.

2.5.2 Disposal Practices Subsequent to the Buffalo Creek Failure

Following the Buffalo Creek failure in February 1972, regulations were promulgated for the design of embankment structures, and programs and resources were developed, including the 1975 Manual to assist in design, inspection and construction of coal refuse disposal facilities. Hundreds of existing and planned refuse disposal facilities were upgraded to new and safer standards, and for slurry impoundments, significant emphasis was placed on dam safety.

The various programs and resources have produced the following major, positive results:

- It has been recognized that coal refuse disposal facilities can represent a threat to public safety and the environment, and positive steps toward eliminating these threats in future disposal operations have been taken.

- The principles of geotechnical engineering, hydrology, hydraulics, and dam-safety engineering have been applied to the design and construction of coal industry impoundments to enhance the safety of these structures.

- There is industry-wide recognition of the importance of coal refuse disposal to preparation plant operation, and disposal practices are being incorporated into the feasibility, planning, and management of mine operations.

- Data that contribute to the application of geology, soil and rock mechanics, hydrology, hydraulics, dam engineering and geochemistry technologies to the evaluation and design of disposal facilities have been collected and analyzed.

- Research has yielded important advances in the prediction of the performance of disposal facilities, and areas have been identified where new research is needed for the design and operation of disposal facilities.

- The potential economic benefit of integrating the disposal facility design into the total plan for coal production operations has been demonstrated.

While effective engineering and design measures have been implemented to minimize the potential for failure of coal refuse disposal facilities, incidents have occurred that may be instructive. A summary of these incidents is presented in Table 2.2.

Challenges remain for the coal industry, including the following:

- Advances in mining technology, including the more widespread application of longwall mining systems, increases the potential for subsidence and associated impacts to the overburden strata that must be addressed at disposal facility sites, either as part of siting and new facility design, or to permit mining beneath or adjacent to existing disposal facilities. Additionally, the threat of subsidence from old mine workings at some sites may require evaluation and remedial action.

- Production capacity at mines has continued to increase as a result of larger longwall mining systems and operations with continuous miners, and in some cases more reject material (non-coal rock) is being mined, with a corresponding increase in the generation of coal refuse. This has resulted in larger embankments and impoundments that must accommodate refuse placement at a greater rate.

- Longwall systems and larger mines with high production rates may exhibit variability in the refuse generation rate. Disposal facilities should be planned and designed considering this potential variability.

- Integration of surface mine operations with coal refuse disposal poses opportunities for more efficient construction, provided design issues associated with mine spoil/refuse embankments are adequately addressed.

- Amendments and admixtures have become common, whether as part of operations (transport of combustion ash from power plants to mine sites) or to address environmental requirements (neutralization of acid generation from refuse). These material additions may affect the performance of the refuse embankments and should be considered during the design process.

- Re-mining of existing coal refuse facilities to recover coal has developed into a niche industry. Development plans must be prepared for the safe excavation and removal of coal refuse from disposal facilities while maintaining the original geotechnical and hydraulic design criteria and considering the potential for shutdowns experienced with such operations.

- Slurry impoundments should be designed considering the potential impact of seismic events. While seismic failures of such facilities have not been reported in the U.S., the potential exists at some refuse disposal facilities.

- Multiple regulatory criteria from federal and state agencies with differing perspectives must be accommodated in site selection and design.

TABLE 2.2 COAL REFUSE DISPOSAL FACILITY FAILURES AND INCIDENTS

February 26, 1972: Buffalo Mining Company,
Buffalo Creek, West Virginia

On February 26, 1972, the most destructive flood in West Virginia's history occurred when a coal waste impounding structure collapsed on the Buffalo Creek tributary of Middle Fork. Shortly before 8:00 a.m., the impounding structure collapsed, releasing approximately 132 million gallons of water. The water passed through two more piles of coal waste blocking the Middle Fork. At that time, there were no federal standards requiring either impoundments or hazardous refuse piles to be constructed and maintained in an approved manner.

Around 1957, as part of its surface mining operations, the Buffalo Mining Company (a subsidiary of the Pittston Coal Company) had begun depositing mine waste consisting of rock and coal in Middle Fork. Buffalo Mining constructed its first impounding structure, near the mouth of Middle Fork in 1960. Six years later, it added a second impounding structure, 600 feet upstream. By 1968, the company was depositing more waste another 600 feet upstream. By 1972, the height of this third impounding structure ranged from 45 to 60 feet.

Between February 24 and 26, 1972, the National Weather Service measured 3.7 inches of rain in the area of Logan County and Buffalo Creek. The impounding structure probably failed because foundation deficiencies led to sliding and slumping of the front face of the refuse bank. The waterlogged refuse bank accelerated the failure. The slumping lowered the top of the refuse bank and allowed the impounded water to breach and then rapidly erode the crest of the bank. Upon failure of the refuse bank, the floodwater moved into pockets of burning coal waste.

As result of the flood, 125 people were killed, 1,100 were injured, and more than 4,000 were left homeless. In addition, the flood completely demolished 1,000 cars and trucks, 502 houses, 44 mobile homes, and damaged 943 houses and mobile homes to varying extents. Property damage was estimated at $50 million.

Source: Davies et al., 1972

August 14, 1977: Island Creek Coal Company,
Boone County, West Virginia

An embankment under construction failed at Island Creek Coal Company's impoundment in Boone County, West Virginia, on August 14, 1977. Heavy rainfall overflowed a temporary diversion ditch, causing the water level in the impoundment to rise. Because the embankment was still under construction, storage capacity had not yet reached the required minimum, and the sudden influx of additional water overtopped the embankment. Meanwhile, the water eroded the embankment, reducing its height 23 feet during a two-day period. During this time, 6.8 acre-feet were released, clogging a drainage pipe downstream.

Source: Owens, 1977

December 18, 1981: Eastover Mining Company,
Harlan County, Kentucky

On December 18, 1981, Eastover Mining Company's Hollow No. 3 combined refuse disposal site failed, releasing about 25 million gallons of saturated coal refuse. The operation, which had been permitted for disposal of coarse coal refuse and dewatered slurry "filter cake" that contained approximately 30 percent moisture behind an embankment 192 feet high, had reached 90 percent of its planned capacity. Several factors contributed to the increased pore water pressure in the dewatered fine refuse zone, including: (1) the filter cake layers had not been allowed sufficient time to dry before additional material was added; (2) layers of filter cake were not completely covered with coarse coal refuse; (3) a stream flowed into the impoundment material, increasing saturation; and (4) material used in construction of the embankment did not allow water to seep out. The failure released a mudflow approximately 5 feet deep that traveled 4,400 feet downstream (500 feet in vertical distance) into the community of Ages, Kentucky. One resident was killed, three houses were destroyed and 30 homes were damaged.

Source: Cannon, 1981

April 8, 1987: Peabody Coal Company,
Raleigh County, West Virginia

On April 8, 1987, a breach developed in the principal spillway pipe in the Lower Big Branch impoundment at Peabody's Montcoal No. 7 complex in Raleigh County, West Virginia. The 36-inch-diameter pipe ran through the impoundment and under part of the embankment at a depth of 55 feet. The rupture released nearly 23 million gallons of water, slurry, and fine coal refuse.

TABLE 2.2 COAL REFUSE DISPOSAL FACILITY FAILURES AND INCIDENTS
(Continued)

The exact cause of the accident was not identified but was probably the result of a combination of factors: (1) Heavy snowfall (16 inches of snow with a rainfall equivalent to 1.9 inches), followed by rapid temperature increases and snowmelt, sent excessive amounts of water through the pipe. (2) Two landslides occurred in the slope above the rupture. Although the relative timing of the landslides and the breach is not known, the slides could have caused the pipe to collapse or separate. (3) Erosion of particles near the pipe connections could have reduced the bearing strength of the pipe. (4) The strength of an "elbow" in the piping may have been exceeded by massive and rapid fluid flow. In addition, a sinkhole that developed from the rupture threatened the stability of the embankment. The sinkhole came within 100 feet of several upstream-constructed additions to the cross-valley embankment before stability was maintained through mitigation of the breach.

The impoundment, upstream from several communities, was rated at the time as high hazard. A 50-mile stretch of Coal River from Montcoal to its mouth at St. Albans was visibly affected, and five water plants were shut down. Although 1,700 customers' water supply was disrupted in the Racine Public Service District, no human injuries or fatalities occurred as a result of this incident.

Source: Owens, 1987

January 28, 1994: Consolidation Coal Company,
Morgantown, West Virginia

On January 28, 1994, a 5-foot earthen berm failed at a slurry refuse impoundment at the Arkwright Mine in Granville, West Virginia. Heavy rain and melting snow resulted in 30 inches of water collecting behind the berm; it was determined that the 4-inch discharge pipe and rock underdrain at the site were insufficient to prevent water accumulation. The incident released 375,000 gallons of water into the town of Granville. Although no one was injured, three residences directly downstream were damaged.

Source: Betoney, 1994

May 22, 1994: Martin County Coal Corporation,
Davella, Kentucky

On May 22, 1994, a breakthrough occurred at Martin County Coal Corporation's Big Hollow slurry impoundment in Davella, Kentucky. Nearly 32 million gallons of black water inundated an abandoned and sealed-off portion of the mine. The breakthrough resulted either from collapse or water penetration of the Coalburg coal seam bordering the impoundment. Slurry had been impounded 32 feet higher than the coal seam's elevation. The mine's 16-inch, concrete-block seals held the black water inundating the mine, but water broke through portal seals and a coal seam outcrop barrier. Although the slurry level dropped by 6 feet, the embankment structure was not damaged, and no injuries or fatalities occurred.

Source: Stewart and Robinson, 1994

August 9, 1996: Lone Mountain Processing Incorporated,
St. Charles, Virginia

On August 9, 1996, there was a breakthrough at Lone Mountain Processing's Miller Cove slurry impoundment. The evening before the failure, approximately 2.75 inches of rain had fallen, and most of it within an hour and a half. Approximately 1 million gallons of black water were released into Gin Creek through an abandoned mine. (Underground mines had operated in areas adjacent to the impoundment from the 1920s to the 1980s.)

Excavation of the breach showed that the leak occurred in an area where available mine maps indicated a barrier of at least 25 feet of solid coal between the outcrop and the underground mine workings. Further exploration revealed that the barrier was in fact less than 2 feet thick. It is believed that hydrostatic pressure from the slurry opened cracks in the coal seam and began a piping-type failure. The thin coal barrier was progressively eroded, allowing slurry to flow uncontrolled into the abandoned mine.

Source: Michalek et al., 1996

October 24, 1996: Lone Mountain Processing Incorporated,
St. Charles, Virginia

On October 24, 1996, a second breakthrough occurred at Lone Mountain Processing's Miller Cove impoundment, but in another area of the abandoned mine. This release was more serious than the event in August 1996 because the water contained more solids. Approximately 6 million gallons of water and slurry exited the abandoned mine into Gin Creek and flowed 11 miles, where it entered the Powell River's North Fork. Reportedly, the river was discolored for more than 40 miles.

TABLE 2.2 COAL REFUSE DISPOSAL FACILITY FAILURES AND INCIDENTS
(Continued)

The failure resulted from two large sinkholes that had developed on the northwestern end of the impoundment. When the site was excavated to locate the breach, it was determined that the slurry had entered through a fracture in the mine roof that coincided with these sinkholes.

Source: Michalek et al., 1996

November 26, 1996: Consolidation Coal Company,
Oakwood, Virginia

On November 26 1996, the Buchanan No. 1 impoundment in Buchanan County, Virginia, failed. In the 1960s, the Kennedy coal seam at the site had been excavated by both surface area mining and underground auger mining. After the impoundment was constructed (1984), another company mining underground in the adjacent drainage area apparently intersected the historic auger mine workings, providing a conduit for the slurry.

Coal refuse and slurry from the impoundment broke into an abandoned underground mine and discharged about 1,000 gallons per minute at its peak through two mine portals into the adjacent North Branch Hollow of the Levisa Fork of the Big Sandy River. There was no detrimental impact on the embankment, and no one was killed or injured.

Source: Michalek el al., 1996

October 11, 2000: Martin County Coal Corporation,
Inez, Kentucky

On October 11, 2000, a coal waste impoundment of the Martin County Coal's preparation plant near Inez, Kentucky, released slurry containing an estimated 250 million gallons of water and 31 million gallons of coal waste into local streams. Reportedly, the failure was caused by the collapse of the slurry pond into underground coal mine workings next to the impoundment. The slurry broke through an underground mine seal and discharged from mine entrances 2 miles apart into two different watersheds (Wolf Creek and Coldwater Fork).

Although no human life was lost, the release killed aquatic life along the Tug Fork of the Big Sandy River and its tributaries. Public water supplies were disrupted when communities along the rivers in both Kentucky and West Virginia shut down water plants to prevent contamination with black water.

Source: Various issues of the *Herald Leader*, the *Courier-Journal*, and the *Charleston Gazette* from 2000 and 2001; National Research Council (2002)

(NATIONAL RESEARCH COUNCIL, 2002)