

RECLAMATION EXPERIENCE IN IOWA; PAST, PRESENT, AND FUTURE

S. J. Henning, R. O. Pope, and R. J. Hansen

ABSTRACT

Surface coal mine reclamation in Iowa had dealt with re-vegetation of abandoned minelands up until the 1960's. In the late 1960's, Iowa's first reclamation laws were enacted and required grading and planting of mine sites. Additional reclamation laws with more stringent requirements were enacted in the 1970's and subsequently were brought into compliance with the Surface Mining Control and Reclamation Act of 1977 (SMCRA). In anticipation of the SMCRA, Iowa State University leased 37 acres of land underlain with coal and operated its own surface mine from 1975 to 1977. Execution of a mining plan that considered future land-use with the soil available was demonstrated. Post-reclamation research at this site since 1978 has dealt with crop production capabilities and soil redevelopment. The restoration of crop production capabilities from reclaimed soils is dependent upon the amelioration of soil compaction and especially that of the subsoil. The re-development of Iowa's coal mining industry is expanding the extent of affected lands. Research is continuing now to restore the agricultural capabilities of mineland for the future.

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Coal lies under a significant portion of Iowa in an area between the southeast and southwest corners of the state and to Fort Dodge in northcentral Iowa. At the turn of the century, coal mining occurred mostly from Fort Dodge to the southeast corner of the state in an area parallel to the Des Moines River. Much of the coal at this time was mined underground but some surface mining did occur. An inventory of abandoned minelands shows that over 15,000 acres of land had been surface mined by 1970. Most of this mining occurred near coal outcrops along river and stream valleys. At one time, nearly ten million tons of coal were mined annually in Iowa, placing it among the largest coal producing states in the country. Iowa's coal mining industry declined as diesel replaced coal to fuel railroad locomotives across the prairies. At the same time, coal fields in Illinois were developed and captured markets in midwestern cities previously supplied by Iowa coal.

Iowa's coal mining industry revived in the early 1970's during the energy shortage resulting from the Middle-east oil embargo. Shortages of petroleum-based fuels prompted the state to examine its own coal resources as a fuel source. The resulting research became known as the Iowa Coal Project. In this project, Iowa State University leased and operated a surface coal mine from 1975 to 1977 in Mahaska County, Iowa (the Iowa Coal Project Demonstration Mine). From 1978 to 1985, this site was leased and operated by the Iowa Agricultural and Home Economics Experiment Station to conduct reclamation research on crop production capabilities and mineland soils re-development.

As the Iowa coal industry expands to meet energy needs and market demands, surface mines are being developed beyond the coal outcrops found along river and stream valleys. New equipment and technology allow coal mines to extend into the broad, flat divides between valleys

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where prime farmland soils are found in this portion of the state. This trend will continue and subject an ever-increasing amount of Iowa farmland to surface mining.

Iowa Coal Project Demonstration Mine

The Iowa Coal Project Demonstration Mine site is located approximately 45 miles southeast of Des Moines, Iowa in Mahaska County, a historic coal mining district in the state. Iowa State University leased 37 acres of land that were underlain with 28 acres of coal. The excess land was used for stockpiling topsoil, subsoil, and overburden and construction of a sediment control structure. Soils mapped as prime farmland occurred on 8 acres of this site. The topography of the site was that of a hillside above a stream with its associated flood plain. The elevation of the coal was above the stream which had truncated the coal seam.

Reclamation of the site required a plan for growing row crops of corn and soybeans (the land use objective). Before mining, a corn/hay rotation was used on the steep, sloping hillside with hay dominating the rotation because of the erosion hazard. Continuous row crops such as corn and soybeans could be grown on a relatively flat flood plain. In order to achieve the project goals, a reclamation plan was developed to build a series of parallel, benched terraces to reduce the erosion hazard that would otherwise impede row crop production. The details of reclamation planning for the Demonstration Mine are presented by Henning and Colvin (1977).

Reclamation was carried out at the Demonstration Mine concurrent with mining. It accomplished two things: (1) the soil was saved and returned to the site and (2) the topography was developed for the intended land use. Mining and reclamation were completed in 1977 and corn was successfully grown in 1978, the following year. Henceforth, the research on this site concerned agricultural management of a reclaimed soil.

A management corn yield goal was established at 150 bushels per acre and probably reflected the optimism that affects farmers during the spring each year. Later, this goal was examined in detail. Although

the site was not mined under SMCRA, the intended crop production goals were established to be equal to or greater than the pre-mining yields. To determine what the yield goals should be at the Demonstration Mine, soil survey information and county yield records were inspected. Three soil series occurred at this site in five mapping units. Table 1 identifies each and gives their corn suitability rating (CSR), land capability classification (LCC), and area.

Table 1. Soils and corn suitability of soils at the Iowa Coal Project Demonstration Mine - Mahaska County, Iowa.

Soil Mapping Unit	LCC	CSR	Acres
Colo silty clay loam ¹ , 0-2%	Iw-2	80	5
Colo silty clay loam, 2-5%	Iw-3	75	3
Clinton silt loam ² , 5-9%, eroded	IIIe-1	63	12
Clinton silt loam, 9-14%, eroded	IVe-1	59	12
Boone fine sandy loam ³ , 18-40%	VIIIs-1	1	5

¹Fine-silty, mixed, mesic Cumulic Hapludoll

²Fine, montmorillonitic, mesic Typic Hapludalf

³Mesic, uncoated, Typic Quartzipsamment

The USDA LCC system is defined as a qualitative method that assesses soil limitations for agricultural use rather than productive capacity. The Roman numeral indicates the number of limitations with Class I having none or very few while Class VII has so many that it should not be used for agriculture at all. The small case letter indicates the subclass that defines the type of limitation such as e for erosion hazard or w for wetness. Finally, the Arabic number is used to identify capability units within the subclass. These capability units with their suggested land use are given in specific county soil survey reports.

CSR's are an index procedure developed in Iowa to rate each soil for its potential row crop productivity (Miller, 1935). It is based on a scale of 100 for a soil unit best suited for corn production. For the Demonstration Mine, a weighted CSR of 57 was obtained. The weighted CSR of land used for corn production in Mahaska County was approximately 73

during the period of 1973 to 1982 and the average county corn yield during this period was 100 bushels per acre. Over the same ten-year period, corn yields in the county ranged from 49 to 128 bushels per acre. Consequently, the yield goal for the mine site should be 57/73 of the counties 10-year average yield or 80 bushels per acre. However, the natural variation in weather over the period would result in yields ranging from 38 to 100 bushels of corn per acre.

Recent work by Thompson (1986) has shown that there are six factors to be considered when calculating the effect of weather on corn yields. They are (1) preseason precipitation (September through June), (2) June temperature, (3) July rainfall, (4) July temperature, (5) August rainfall, and (6) August temperature. With the appropriate coefficients, a quadratic equation can be solved to determine weather's effect on corn yield. Further applications of this work have enabled Thompson to quantify the impact of technology on corn yields from the 1930's to the present time.

A planting rate of 22,000 kernels per acre was chosen to achieve the 150 bushel goal. This rate was derived by determining the weight of ear corn in pounds and dividing that by a desired ear weight of one-half pound. Farmers in the area will plant 27,000 to 30,000 kernels per acre on their better land hoping to achieve yields of 200 bushels per acre.

Initial soil test results of the reclaimed soil showed an average pH of 6.8, 9 pounds available phosphate per acre, and 100 pounds available potash per acre. The soil organic matter was low and variable across the site. Nitrogen was applied at 150 pounds of N per acre, phosphorus and potassium were applied at 100 pounds per acre of P_2O_5 and K_2O per acre. Three tons per acre of ground limestone with an average effective calcium carbonate equivalent (ECCE) of 50 percent were also applied to raise the soil pH to 6.9 or greater. Limestone was applied only once, but nitrogen, phosphorus and potassium were applied each year. The fertility program was maintained at this high level in order to increase the amount of plant available-phosphorus and potassium in the reclaimed soil. After five years, available phosphorus and potassium were approximately 50 and 170 pounds per acre of phosphate and potash, respectively.

To summarize the status of soil fertility management on reclaimed soils, soil testing can determine the amount of plant-available nutrients from which recommendation of an appropriate quantity to add as fertilizer can be made. Secondly, plant available nutrients, except nitrogen, in the reclaimed soil can be increased by use of a fertility program designed to build up soil test levels in addition to meeting plant demands. Finally, soil pH of reclaimed soil where no pyrites are present can be easily adjusted by determining an appropriate amount of limestone to be applied from a calibrated soil buffer pH test.

RESULTS

Corn was grown at the Demonstration Mine with some success from 1978 to 1984. Yields for this period were as follows: (1978) - 67.7; (1979) - 84.0; (1980) - 75.1; (1981) - 122.7; (1982) - 65.3; (1983) - 0, and (1984) - 31.8 bushels per acre. The average yield through the period was 70.9 bushels per acre or ten bushels less than the minimum yield goal that was set for the site. Weather had a dominant and variable effect on corn yields from year to year as was best illustrated in 1983, when a complete crop failure occurred.

Throughout the period, the pest control methods worked well. The soil fertility program supplied all the phosphorus and potassium required by the corn but nitrogen deficiency symptoms were visible where water stood for extended periods of time. Water on the surface of plots where minor settling of the soil had occurred. Differential settling interfered with drainage and farming operations as well. Drainage into the soil of the ponded water was very slow because compaction was so severe in the replaced subsoil.

The effects of weather were compounded by soil compaction in the reclaimed soil. In the spring of a wet year, the soil was very difficult to work and subjected the corn crop to uneven emergence. If the soil became saturated, denitrification of nitrogen fertilizer occurred and robbed the plant of this yield building nutrient. Similarly, in very wet years saturated soil conditions and high soil strength would prevent the deep root penetration (3-5 feet) that would be needed later in the growing season for moisture extraction when moisture in top few inches of soil had been removed by the crop.

The problem of soil compaction was investigated by determining the soil bulk density, volumetric water content, and saturation percentage of soil cores obtained to a depth of two feet. In this study, soil that had been maintained in continuous corn production was compared to soil where alfalfa had been grown (Table 2).

Table 2. Calculated physical properties of soil from continuous corn and alfalfa plots.

Crop	Soil depth (inches)			
	6	12	18	24
	<u>Bulk density</u>			
Continuous corn	1.41	1.44	1.48	1.63
Alfalfa	1.43	1.42	1.58	1.58
	<u>Volumetric water content - percent</u>			
Continuous corn	34.5	35.3	36.4	32.8
Alfalfa	29.7	29.7	26.0	26.7
	<u>Saturation - percent</u>			
Continuous corn	74.4	77.1	82.7	84.9
Alfalfa	64.7	64.6	64.9	68.7

The soil density data from the corn plot show sharp density increases at depths between 18 and 24 inches. Corn root penetration into the soil can be expected to be greatly impeded at values beginning at approximately 1.50 Mg/m³. Consequently, little water extraction would be expected below 24 inch depth. It is interesting to note from these data that soil from under corn and alfalfa had similar densities except at the deepest depths, and that where alfalfa had grown, the volumetric water content was less, hence the percent saturation of the soil was also less.

Recommendations

Soil compaction as it relates to agricultural productivity is a central problem in the reclamation of minelands, especially in the Corn Belt where row crop production is given the top priority of land-use

options. Yet the deleterious effects of compaction are tempered by the soil's tilth, that unique property of soil that includes bulk density, available water-holding capacity, texture, structure, soil strength, organic matter content, mineralogical makeup and others. Measurement of the combined effects of these parameters is difficult, but that is what is necessary.

Voorhees (1983) states "Penetrometer resistance is probably a more sensitive indicator of soil [compaction] amelioration than bulk density determination because the latter is sensitive to pore volume and insensitive to fracture planes or weakness." He adds that although water content and bulk density of soils can considerably affect soil penetration-resistance values, in some cases (on agricultural soils) it has been shown that the effects of variable water content on penetrometer readings can be controlled so that the results have meaning. However, Voorhees found in his study that the effect of the soil water on penetrometer resistance was best quantified at relatively low densities and generally became increasingly more difficult as soil bulk density increased. This indicates a need for more defining research in mineland applications, since soil bulk densities encountered are in or above the highest range studied by Voorhees. Additionally, a properly calibrated portable recording penetrometer is promising as a tool in the estimation of the "return to productivity" because of the large number of readings possible in a given time relative to other traditional soil strength measuring instruments.

Natural Amelioration

Soil compaction can be alleviated in nature by several related processes that are all time-dependent. These include effects from wetting and drying, freezing-thawing, and the intrusion of macrofauna (e.g. earthworms) and roots into the soil along planes of weakness. These processes physically force the opening of fissures and micro-cracks. Repeated cycles of wetting and drying in compacted soils result in volume change of certain expandable clay minerals, a process that is referred to as shrink-swell. The forces generated within a soil mass by clay shrink-swell cause the development of cracks along existing planes

of weakness, resulting in a general increase in porosity and, in turn, improved water transmission characteristics in the soil. Normal seasonal wetting and drying cycles are important in the shrink-swell process, but the introduction of plant roots that remove water can extend both the depth and occurrence of desiccation and re-wetting effects within the soil mass.

Gill (1971) observed that freeze-thaw effects on the structure of agricultural soils were likely limited to areas roughly north of the 38th parallel, where the soil freezes annually to a minimum depth of 38 centimeters. Two freeze-thaw phenomena can be considered in the alleviation of soil compaction; physical expansion of soil water at temperatures near freezing, and the redistribution of soil water in response to changing water potentials due to the conversion of liquid water to solid water (ice) near lenses and other segregated soil ice forms. Water reaches its lowest density, that is, it occupies the greatest volume, at approximately +4 degrees C. It is unlikely that the force exerted as a moist soil freezes is great enough by itself to significantly reduce soil bulk density. However, the development of planes of weakness in a soil from water volume changes alone cannot be discounted as a factor in allowing other compaction alleviating forces to act.

There are two requirements for the growth of ice lenses at low soil temperatures. First, there must be enough soil water available to establish an effective soil water potential gradient, and second, there must be adequate initial porosity to allow for the movement of water along the potential gradient to the growing ice body. But the development of ice lenses is unlikely on mineland soils; initially at least, reclaimed soils will be too dense for sufficient water conductivity except where soil materials have been loosened mechanically.

Whether ice lens formation is beneficial in reclaimed soil is questionable. Evidence suggests that platy soil structure develops where lenses have occurred. Platy structure orients soil material in horizontal directions, effectively forcing water to move laterally as

well as downward. The additional movement decreases the rate of drainage through the soil.

The effects of flora and fauna on improving minesoil tilth are of great potential importance. Mention has been made of the development of fracture planes, desiccation cracks, or "planes of weakness" within the compacted soil mass. Plant species with roots capable of growth into the soil materials with high mechanical impedance (high soil strength) and tolerance to adverse soil water conditions can take advantage of these planes to explore more and more of the soil mass. As roots grow through these cracks, they allow water from the surface to reach greater depths and they also extract water, effectively drying the soil mass, which contributes to formation of further desiccation cracks. Consequent and subsequent faunal activity is encouraged by proper vegetative cover, resulting in temporally mediated amelioration of reclaimed soil in the Corn Belt.

Possibilities

Productivity must be demonstrated on reclaimed land under the Office of Surface Mining's Permanent Program Performance Standards³ (PPPS). PPPS section 823.15 b-5 states, "Restoration of soil productivity shall be considered achieved when the average yield during the measurement period equals or exceeds the average yield of the reference crop established for the same period for unmined soils of the same or similar texture or slope phase of the soil series in the surrounding area under equivalent management practices." Corn is expected to be in this comparison because it is the dominant row crop in the Corn Belt. The use of a dominant row crop is addressed by PPPS 823.15 b-6 which states "The reference crop on which restoration of soil productivity is proven shall be selected from the crops most commonly produced on the surrounding prime farmland. Where row crops are the dominant crops grown on prime farmland in the area, the row crop requiring the greatest rooting depth shall be chosen as one of the reference crops."

³"Mineral Resources", Code of Federal Regulations Title 30, Pt. 700 to end 1986 rev.

Corn today is a surplus commodity in the Corn Belt. The fence-row to fence-row farming goal of the 1970's no longer should be a driving force to re-establish productivity on reclaimed land. The emphasis today must rest with utilizing land for its capability and setting aside from production those lands which present an erosion hazard. This changed attitude, brought about by a marginally profitable agricultural economy, in turn suggests new possibilities for reclamation in the Corn Belt.

If one scrutinizes the Conservation Reserve Program (CRP) of the Food Security Act of 1985 (PL 99-198), one can see that the goals of the Act are consistent with land management practices that protect the soil, even at the expense of reduced grain production. The Report of the House Committee on Agriculture to Accompany the Food Security Act of 1985⁴ listed the following as necessary goals for a successful conservation reserve:

- protect our long term capability to produce food and fiber,
- reduce soil erosion of land in the program by as much as 20 tons per acre per year.
- reduce sedimentation in streams and along roads,
- improve water quality,
- create better habitat for fish and wildlife through improved food and cover and better moisture conditions,
- provide some needed income support for farmers.

PL 99-198⁵ states, "The term "highly erodible land" means land - (i) that is classified by the Soil Conservation Service as class IV, VI, VII, or VIII land under the land capability classification in effect on the date of enactment of this act; or (ii) that has or that if used to produce an agricultural commodity, would have an excessive average

⁴U.S. House of Representatives. 99th Congress. 1985. Food Security Act of 1985. Report of the Committee on Agriculture to Accompany HR. 2100. Rep't. 99-271, Part 1. Washington D.C.

⁵"Conservation". Food Security Act of 1985. PL 99-198. Title XII, 99 Stat. 1504-5. Washington, D.C.

annual rate of erosion in relation to the soil loss tolerance level ..." Applying these concepts to the Demonstration Mine would have made three soil mapping units available to be enrolled in the CRP. Upon the completion of mining, all the reclaimed soil would be eligible for enrollment because they present an erosion hazard until vegetation is sufficiently re-established to provide it the protection.

Both CRP and PPS show similar concerns for soils but the latter requires production in spite of a changed farm economy and attitude toward production. the objective of demonstrated productivity, though important, must yield to concern for the soil and redevelopment of its potential over the long term.

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RECENT ANALYTICAL DEVELOPMENTS AS RELATED TO
MINED LAND RECLAMATION

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ABSTRACT

In order to carry out the responsibility of soil and overburden handling and revegetation, State and Federal Agencies have requested accurate information on the chemical and physical properties of soil and overburden materials. Guidelines have been compiled and periodically revised in attempts to improve mutual understanding of overburden and soil sampling, analyses and handling programs which enhance successful revegetation and reclamation of areas disturbed during surface mining operations.

Programs have been established which discuss sampling density, sampling intervals and drilling techniques for overburden. These programs are fairly straight forward and easily reconciled in the event of disagreement. Further, the method of soil inventory (as necessary) has been fairly well resolved with most guidelines accepted. The area of concern is that of the policies on analytical determinations.

Analytical programs were established that were designed to obtain all available information about soil and overburden materials. These programs were refined everytime there was a change in personnel in State or Federal Regulatory Offices.

Voluminous data have accumulated over the last couple of decades: most of which was not necessary when obtained, is not used in mine plans and is not necessary for good reclamation. On the next few pages many of the parameters requested will be discussed separately.

ANALYTICAL PARAMETER DEVELOPMENT

pH is a measure of Acid (below pH 7) or Base (above pH 7) content of a soil or overburden material.

EC (Electrical Conductivity) is a measure of the total salt content of a soil or overburden material. The management and need for reclamation of saline soils are evaluated from measurements of such concentrations. These readings are best obtained from saturated soil paste extracts because they best represent field conditions; however they are harder to determine accurately than are such extracts as 1:1, 1:2 or 1:5. As a compromise (to measure relative changes rather than absolute solute concentrations) a 1:1 extract is suggested. Errors from peptization, hydrolysis, cation exchange and mineral dissolution become greater as the ratio of water to soil increases. However, 1:1 or 1:2 extracts are easier to reproduce in the laboratory and comparative values should be more easily correlated.

Soluble Cations (Ca, Mg, Na, K) are the predominant cations of the soil solute. It is important to determine these cations, if and only if, their ratios to each other are important. The predominant need is the SAR value. This value is related to the exchangeable sodium percentage (ESP) and is generally conducted instead of conducting the ESP. Exchangeable sodium reflects the alkali hazard of the soil.

The lignite region of the United States corresponds to high rainfall; therefore we find predominantly low soluble salt - low pH soils. For maximum production of most crops these soils must be limed. The amount of sodium is not generally considered as rainfall generally leaches it below the rooting zone. I say all this to get this point across: when soils or soil materials are acidic, liming (additions of calcium and/or magnesium) is necessary in reclamation; therefore the pre-mine analyses for these ions are not necessary.

A comment made by one colleague is that soluble cation values should be determined to subtract from the exchangeable bases values of these cations for the determination of base saturation percentages. This topic will be elaborated on when determinations of exchangeable bases are discussed.

Soluble anions (OH), CO₃, HCO₃, Cl, SO₄, and NO₃ are the predominant anions of the soil solute. In some soils Boron can be added to this list. These values are requested, but what do we do with them. Yes occasionally a critic will look at the values to compare to the cations. But we don't make changes in mining because they are high or low; nor do we recommend ammendments because of high or low values to these anions. They could be dropped from the suggested list of analytical determinations.

Cation Exchange Capacity is a measure of the total negatively charged sites on the soil clay, silt and/or organic matter which can be occupied by cations. CE is not a soil property that is independent of the conditions under which it is measured. Different results will be obtained with different methods. Ideally the method to use is one that measures the soil's capacity to absorb cations from an aqueous solution of the same pH, ionic strength, dielectric constant, and composition as that encountered in the field. Variations in CEC results are not surprising in view of the many possible interactions between saturating, washing, and extracting solutions and soil constituents during the analysis and the fact that CEC is not an independent, single value soil property.

CEC values of acid soils (similar to those of the lignite region) can be low because the sites are occupied by adsorbed aluminum-hydroxy polymers and/or positively charged mineral particles such as iron oxides. Further the negatively charged sites of some 1:2 latic clays may be occupied by interlayer cations which are not readily exchangeable under laboratory conditions, although they can be desorbed under field conditions.

The CEC value is not used in and by itself in the assessment of soil and/or soil materials as to their use in the reclamation of a mine. CEC values are used to determine base saturation percentages which will be discussed later.

Exchangeable bases (Ca, Mg, Na, K) are those bases which occupy exchange sites on the clay and organic matter of the soil or soil materials. The definition is not entirely straightforward for the acid soils and soil materials of the lignite region. Quasi-exchangeable cations of aluminum, iron, hydrogen and potassium which occupy negative sites with such bonding to prevent exchange alters total exchangeable base values. In the lignite regions the cations most commonly occur in the following order Ca>Mg>K>Na expressed as meq/100g.

As discussed earlier to obtain more correct values of the exchangeable cations, the soluble cations (determined on the water extract) should be subtracted from the extractable values because the extract for exchangeable removes the soluble bases also. However when expressed as meq/100g the sum of soluble bases is equal to the E.C. value expressed as mmhos/cm at 25°C.

Base Saturation Percent: The ratio of each exchangeable cation to the others occupying the exchange is not used in assessment of soil or soil materials as a topsoil source. Instead, the sum of cations along with the CEC values are used to determine the base saturation percentages (SP).

Now, since:

E.C. = Soluble bases (Ca, Mg, Na, K)

The actual sum of exchangeable bases equals the sum of extractable bases minus the soil E.C. value then.

$$SP = \frac{100 \quad (\text{extractable bases (Ca, Mg, Na, K) - E.C.})}{\text{CEC}}$$

where: extractable bases and CEC are expressed as meq/100g and EC is expressed as mmhos/cm.

Now that we have discussed the exchangeable bases: how are the values used in reclamation? Because the ratios of cations are not used; the only use is that of base saturation percentages. These values are only used to correlate with those of acidity and pH to classify undisturbed soil pedons.

Along with the CEC values: neither the exchangeable bases nor the base saturation percentages (SP) are used to any large extent in the mine plan. On occasion SP values are used with pH values in calculating lime requirements of the reclaimed land. Such lime requirements can be obtained without the SP value through using buffer pH values (SMP).

Organic Matter Percent - (Easily Oxidizable) of soil or soil materials influences the capacity of the material to supply N, P, S and trace metals to plants. For dragline operations (those of the lignite region) selective placement of organic matter for topsoil is not practical. Nitrogen and phosphorus are commonly added to the soils of the region to enhance vegetative production. Organic matter is generally incorporated on the surface during the reclamation.

Available Nitrates Nitrate nitrogen is an important source of plant nutrients. Further, in large amounts it can cause contamination of surface and ground waters. Because nitrate nitrogen is very soluble it will move through the soil or soil materials and values may vary every time the soil is analyzed. Nitrogen must be added to the soil or soil material in the reclamation of the land, so why, why analyze pre-mine. If there were to be a possibility of nitrate contamination it would be picked up in the pre-mine water analyses.

Available Phosphorus like nitrate nitrogen, is important to plant production. However, it is not as mobile as nitrate nitrogen. Therefore, to place soil or soil material with proper amounts of this element at the surface would require intense special handling of all lithologic materials. This would not be cost effective. No one looks at phosphorus as a contaminant so why bother to analyze pre-mine for the element. We have to apply phosphorus to reclaimed surface for optimum plant growth. If testing is needed it is on the reclaimed surfaces.

Available Potassium is like nitrate nitrogen and phosphorus. The potassium contents of the land pre-mine does not affect the amount required on the reclaimed land.

Available Trace Elements are those trace elements which have been analyzed for by the research personnel and found to be most important as a fertilizer. They are iron (Fe), Manganese (Mn), Copper (Cu) and Zinc (Zn). Again, why do we analyze all lithologies for these trace elements? Their amounts only in the surface of the reclaimed mine sites are important to plant growth.

Exchangeable Acidity (EA) has been added as a parameter necessary to assess the potential acidity of mine spoils in recent years. This is a result of studies conducted in Texas. However, the use of such data has not been totally confirmed. In other words, there exists controversy as to the use of EA in assessing potential acidity of mine spoils.

Exchangeable acidity is a fairly arbitrary quantity composed of four types of acidity: (1) hydrolysis of exchangeable Aluminum, (2) hydrolysis of partially hydrolyzed and nonexchangeable Aluminum (3) weakly acidic organic materials and (4) exchangeable hydrogen. A measurement of exchangeable acidity is better than a value obtained by saturation of exchangeable bases from the cation exchange capacity. There are two parts to exchangeable acidity. The first is a part related to the immediate need for lime and the second part related to the potential lime needs to maintain higher pH values.

Maintenance of an appropriate pH of the surface soil assures multi-conditions favorable to plant. Adequate base saturation of the soil exchange sites is provided; solubilities of elements toxic to plants at lower pH are decreased and thereby rendered nontoxic; some plant-essential elements become more available; and the soil is more favorable for optimum microbial activity.

In the lignite region many of the overburden strata are acidic. Selectively placing non-acidic materials at the surface is not practical at most mines. Therefore, liming surface materials to desired pH levels is the most appropriate method of obtaining optimum pH values of the soil or soil materials.

There are lime requirements (LR) tests that may be well used instead of determining the exchangeable acidity. In the lignite region low pH materials cannot always be specially handled.

Acid-Base Account is a relation that has been established as the value used to determine the amount of lime (tons CaCO_3 /1000 tons material) necessary to add to or remove from the overburden materials to neutralize the system. Little concern is given to materials high in calcium

carbonate (generally those with pH values above pH 7.0). However, those materials which require more than 5.0 tons CaCO_3 /1000 tons material has been restricted from placement (in most instances) within the rooting zone without proper treatment to neutralize the acidity.

Acidity may occur because of acid spoils, but acid groundwaters presently occur in many of the areas where lignite coal is mined. Plans must be implemented to obtain maximum quality of the environment. These plans must also be cost effective. The acid-base account is one of the most important values in assessing handling of mine spoils.

Potential Acidity (PA) originally was calculated from the total sulfur value. If the total sulfur were to be from pyrites, then that value would correspond to the actual potential acidity. But if part of the sulfur occurs in other forms, the maximum potential acidity would be too high. Likewise, if one is to consider the total acid that must be neutralized he must also include the exchangeable acidity (EA) along with that from sulfur forms.

When the maximum total acidity (Total Sulfur) values are low, within safe limits, then the determination of sulfur forms (sulfate, pyrites and organics) are not necessary and the lime requirements will be that of the exchangeable acidity (EA).

Neutralization Potential (NP) is a value given to the amount of acid (expressed as tons CaCO_3 /1000 tons material) necessary to neutralize the material. In the event that the material is already acidic the value is a negative value. This is the case for many overburden materials of the lignite region.

Trace Element Analyses. With the exception of Boron (B), the request for trace element analyses are on a total elemental basis. The number of elements requested varies and the greatest environmental concern is placed on these analyses. The reason for this is that many of these elements (in the right oxidative state) is toxic to plants, animals and/or man and are sometimes believed to be carcinogens.

Availability indexes are generally requested for Boron since it is an essential plant nutrient that can if high enough be toxic as well. The levels have fairly well been established; therefore hot water soluble boron techniques are incorporated as the method of analyzing boron.

Unfortunately, the availability, plant uptake and weathering data of non-plant essential trace elements has only recently (recently meaning the last couple of decades) been researched. Data which can be used in mine spoils situations to correlate different extracting procedures to trace elements in the environment after land disturbance is limited. Therefore, total digests are required at the present time. These data gives us total potential trace element hazard, instead of what will actually occur.

Total potential hazard of trace elements may have little value. If the trace elements are in the forms of chlorides, sulfides, carbonates or sulfates they may become readily available, but if they are in the rock form or clay lattice they may never become available. Further, most trace elements of concern become more available at lower pH values, with the exception of Molybdenum. If pH values in the materials are maintained at higher levels the elements will not be available.

Now, concerning the elements included in most lists to be analyzed by regulatory agencies. Why is the plant nutrient elements requested? Spoil materials are not going to be handled to place zinc, iron, copper or manganese on or near the surface when it is more economical to add them as a fertilizer source.

Naturally occurring Chromium can occur in soil from as low as 5 ppm to as high as several percent and not be taken up by the plants or be harmful to water or mankind. The reason being these naturally occurring Chromium compounds are generally chromites which are chemically quite inert. Normally Chromium problems come principally from the man added Chromium pollutants of Chromium III cations and Chromium VI. Total values for Chromium obtained from the soil or overburden materials may not have much meaning.

Those elements of most concern should be Arsenic, Selenium, Cadmium, Lead and possibly Nickel or Uranium. They are more likely to become available in the environments of lignite mine spoils than in the higher pH spoil materials of coal mines in the West.

Texture is one property that has a large influence on many of the properties previously discussed. Materials with higher clay contents have higher cation exchange capacities and water holding capacities. The texture affects the exchangeable cation content, the base saturation percentage and the exchangeable acidity.

Texture is easily determined and can be easily reproduced unless sample handling and/or grinding techniques vary.

Pyritic Sulfur is determined and reported in the analyses for acid-base accounting. It is an important analyses in assessing potential acidity of a spoil material. Analyzing for pyritic sulfur is not necessary if the total sulfur values are low and/or neutralization potentials (NP) are high.

Exchangeable Aluminum (AL) is used to correlate to the pH values when pH values are low. Many times the lower pH value is a result of hydrolyzed aluminum. The value is good if it is necessary to determine causes of low pH; but if lime requirements are determined without concern to the cause of such pH values then such analyses may not be necessary.

Exchangeable Iron (Fe) is also used to correlate to the pH values when pH values are low. The same comments apply to exchangeable iron that applies to exchangeable Aluminum.

Available Moisture (1/3 and 15 ATM pressure) is sometimes requested on soil materials. These data are only used to correlate the soils to specific soil series and generally not used there. It is not fully understood why it is necessary to determine the available moisture when such data can be extrapolated to a near proximity using texture.

Organic Carbon analyses of soils is also a parameter used by correlators in soil classification. Since most soils are either already correlated or are variants of existing soil series for the region, one might question the need for such analyses.

Bulk Density is a physical parameter which is used if compaction occurs in an area. This value is more appropriately taken post-mine in areas of haul roads, etc. than in an assessment of a mine area.

ANALYTICAL PARAMETER SUMMARY

As a summary, many analyses are now collected because the regulatory agencies use them to correlate with each other. It seems more logical to prepare standard samples which must be analyzed by the laboratory conducting the analyses, with the results having to fall within a specific confidence interval for the data to be accepted. Then only necessary parameters need be conducted.

Further, in the pre-mine analyses it is not necessary to conduct analyses which cannot be used to either improve or prevent destruction of the environment. For example: pre-mine analyses for nitrates, available index of phosphorus, potassium, zinc, iron, copper, manganese and boron (all plant nutrients) are not going to alter placement and treatment of soils or soil materials in a post-mine reclamation plan.

Tests like pH, SMP Buffer, E.C., texture and potentially hazardous trace elements may be all the chemical data necessary for the pre-mine soil assessments. These data along with a good soil survey map (order 1 where disturbance is to take place) and correlated profile descriptions should properly describe the soils as to their capability to produce vegetation and treatments (lime, fertilizer, etc.) necessary to obtain maximum productivity.

The tests mentioned for the soils along with an acid-base accounting may be all that is necessary for the proper placement of mine spoil to obtain the best environment. Such placements should result in good ground and surface waters as well as optimum vegetation on the reclaimed surface.

ANALYTICAL PROCEDURES AND INSTRUMENTATION DEVELOPMENT

Analytical procedures have not changed much over the past 20 years except when they were changed from wet chemistry determinations to instrumental determinations. There has been great changes in instrumental analyses. Instrumentation has gone from small spectrophotometers and flame photometers where each sample was read individually from a needle deflection to the present excellent atomic absorption, plasma; neutron activation and x-ray fluorescence with autosamplers and multielement analyses with computer printout of results. Detection limits have been improved; but more importantly, accuracy and precision has improved.

The limiting factors and the variability obtained is generally a result of sample preparation and handling in the case where these type instruments are used. Unfortunately, not all laboratories can afford these instruments.

Should all companies go to laboratories with the advanced instruments? The prices are higher using such instruments, but the data is generally more accurate! It appears that presently there is a trend to get the analyses at the cheapest cost seeing that the data is not used much anyways. Therefore smaller laboratories must improve their quality control. One way is to require blind samples supplied by the regulatory agency be included in with the samples as discussed earlier.

Another way to cut the analytical costs is to use test kits like those used in hospitals. If we can trust our lives to analyses from kits then we can trust the analyses from mine sites to similar kits. I see this as a great possibility for the future.

In the future the instrumental companies may have to face a reduction in the price of their instruments as foreign made instruments with as good or better detection limits and accuracy are imported into the United States.

Analytical models may be established which fits the lignite region of the Southwest or other coal regions of the United States. The analytical program for each mine could then be refined and the cost reduced because sample numbers can be reduced. Analyses would only be necessary for elements and compounds found to present a problem or which may enhance the reclamation of the mine.

ANALYTICAL PROCEDURES AND INSTRUMENTATION SUMMARY

Analytical programs have been dynamic during the last couple of decades. There has been a continuous change in the parameters requested as well as the extraction methods. Also at the same time, trying to maintain a competitive pricing structure, laboratories installed more refined and better instrumentation. Lower detection limits were established. But where do these programs stand today?

The recent policies of State and Federal Agencies has been to establish guidelines, requesting that specified procedures be used for parameters. It is necessary to follow up with quality assurance programs for laboratories that will insure quality data. By doing this, parameters can be eliminated that are used by these agencies to cross check lab data. The use of new instrumentation should be verified by comparative statistical data supplied by the laboratory or instrument company. It is time to prepare analytical models, analyze only required parameters by representative extraction procedures to supply the required data for the model and have data that can be used to predict future environments.

Federal Regulation of Utility Ash Disposal
A Status Report

Abstract

By virtue of a 1980 amendment to RCRA, electric utility ash disposal is exempt from federal regulation pending completion of an EPA study on the effects of ash management and a recommendation to Congress on appropriate regulation. EPA's study is nearing completion. Based on numerous tests of its ash, the utility industry believes its coal ash to be nonhazardous and has provided EPA with evidence supporting this conclusion. The industry further intends to participate in EPA's call for suggestions on revisions to its nonhazardous waste regulation program, and will offer demonstrations that its combustion by-products can be safely disposed of using commonly available engineering analysis tools

Federal Regulation of Utility Ash Disposal
A Status Report

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In 1976, Congress passed, and the President signed, the third major federal law empowering the Environmental Protection Agency to clean up the nation's environment. The Resource Conservation and Recovery Act empowered EPA to define and classify solid wastes as either "Hazardous Wastes" or "Solid Wastes" and regulate all aspects of their management and disposal. In addition to dividing all wastes into just two categories, Congress also specified that EPA could directly regulate hazardous wastes, but had to leave the burden of regulating solid wastes to the states, with no more federal input than non-enforceable guidelines. We will shortly see the problem this has caused utilities and other industrial waste generators.

The electric utilities collectively product about 60 million tons of combustion residues annually. These are in the form of fly ash, bottom ash, slag and scrubber sludge largely from the burning of coal, but also from burning oil. Through diligent marketing efforts, about 25 percent of this combustion residue is reused either as fill material or in ways that take advantage of the chemical properties of ash. The remaining 75 percent of the material, which we will collectively call ash, is disposed of either on-site, off-site, in ponds or dry landfills. Naturally, the utilities are interested in retaining and expanding ash reuse because, aside from any revenue gains it may produce, it reduces the national cost of disposal by about one quarter. Surveys of ash reusers has revealed that a hazardous classification of ash would cause them to shun the material, effectively putting an end to reuse. The utilities recognized the potential of RCRA to seriously impact their disposal cost as well as affecting ash reuse. Exactly how they would be impacted had to await the promulgation on regulations by EPA.

One of EPA's early proposals for regulation of utility ash was through the mechanism of a Special Waste category. With little evidence in hand as to the environmental impact of ash disposal, EPA nonetheless decided so large a universe of waste probably required careful federal control. At this, the utility industry sprung into action. The recently formed (1978) Utility Solid Waste Activities Group, representing most coal and oil burning utility companies sought to demonstrate to EPA that, on the one hand, a special waste category for ash would carry the stigma of a hazardous waste and reuse would disappear. On the other hand, traditional means of ash disposal did not pose a significant threat to the environment. The utility industry efforts, combined with the coal industry culminated in 1980 in the Huddleston-Bevill Amendment to RCRA. This amendment instructed EPA to forestall federal regulation of coal ash until the agency had studied its impacts on the environment. EPA was to prepare a report to Congress by October, 1982 with its findings, and to propose appropriate regulations six months later.

The amendment instructed EPA to address a number of matters including the sources and volumes of utility ash, the methods of managing these wastes, the environmental impacts of disposal, documented cases of adverse impacts, effects on coal use and reuse of federal regulation and the costs of regulation on ash management. EPA had already contracted for a study of utility ash disposal which addressed some but not all of the issues raised in the amendment. Unfortunately, this study was somewhat slow in getting underway. It eventually included a detailed analysis of six power plants and their ash management practices, but had hardly gotten started when the October, 1982 report deadline had passed.

USWAG, seeing the inadequacy of the agency's report in addressing all the points raised by Congress undertook its own investigation of its members' ash disposal operations. All of the points in the amendment were addressed, but the cornerstone of USWAG's study was an analysis of groundwater monitoring data at 31 ash disposal sites. The results were incorporated in a three volume report, submitted to EPA in October, 1982. The conclusion, broadly stated, were that while there was evidence that leaching of chemical constituents of ash into groundwater commonly occurs, in very few cases were these effects sufficient to degrade groundwater quality sufficiently to render it unsuitable as drinking water. The following year was spent by USWAG discussing the management of ash as practiced by utilities with the EPA staff members responsible for drafting the report to Congress, as the agency struggled with limited resources to complete this and other congressionally mandated studies.

As this is written, the EPA report to Congress on utility ash is still not complete. A recent conversation with Dr. Winston Porter, Assistant Administrator for Solid Waste reveals that the draft is essentially complete, and submission to Congress is expected in October 1987.

What will the report say? We will not know until it is made public later this year. There are, however, certain things we do know as a result of regulatory activities that have taken place since the Huddleston-Bevill Amendment was passed seven years ago. For one thing, EPA promulgated rules for the classification of wastes as either hazardous or nonhazardous. We know that utility ash, when subjected to the Extraction Procedure (EP) for determining whether a waste is hazardous by virtue of toxicity, almost never fail. Of the hundreds of analyses of utility ash that we have seen, virtually all are found to be nonhazardous. Less than two percent of the wastes analyzed are hazardous, and some of these are undoubtedly anomalous results. We have less experience with the TCLP, which is the proposed replacement of the EP. But from information now in hand, it appears that results will be somewhat similar. EPRI recently undertook a project to analyze a limited number of ash samples using the proposed TCLP and one out of ten ashes failed the test due to leachate concentrations of one of the test metals being slightly higher than the standard. It should be emphasized that the TCLP, as a procedure is still not final and is undergoing considerable scrutiny at EPA because of public comments received. In any case, the metals levels against which ash is tested, are likely to change from the

present one hundred times drinking water standards. EPA has indicated that the metals standards may be revised through the use of the back-calculation methods and Monte Carlo techniques proposed last year as the method it will use to calculate standards for organic chemicals.

Another important development that may provide a clue as to EPA's mood with respect to high volume, low toxicity wastes is the completion last year of the mining waste study. EPA was charged with studying management and disposal of mining wastes by Congress. EPA's mining waste report concludes that, with a few exceptions, mining waste should not be regulated as a hazardous waste under RCRA Subtitle C, even though some of these wastes do test hazardous by virtue of toxicity. It should be pointed out that the mining waste study has been challenged by environmental groups. The final outcome will have to await what may be a lengthy set of negotiations, or a court decision. Still, EPA's position gives us some idea of the conclusion they may reach in the utility ash study.

Recall that RCRA limits EPA's authority to directly regulate to hazardous wastes only. Nonhazardous wastes are primarily the responsibility of the states. EPA has come to realize that many nonhazardous waste landfills can create significant environmental problems. In the case of high volume, low toxicity wastes such as those produced by the mining industry, EPA is not willing to completely relinquish control of the management and disposal of these materials. In the mining waste study, EPA seeks public comment in the form of suggestions on how it might exercise some direct control over a nonhazardous waste normally falling under RCRA Subtitle D. Nor is this call for ideas limited to mining wastes. EPA has begun its planned review of its whole Subtitle D program with an eye toward reducing the environmental problems resulting from nonhazardous waste disposal. This brings us to the second major undertaking by USWAG to ensure that utility ash is regulated in a way that is conservative of resources as well as protective of public health and the environment.

Until now, USWAG based its case for reasonable regulation on data relating to past and present disposal operations. The underlying argument has been that, absent any federal regulations governing ash disposal, this activity seldom has resulted in significant environmental degradation. True, there have been instances of, for example, groundwater degradation serious enough to warrant corrective action at specific sites, but the states and the utilities themselves have proven themselves capable of handling these cases without the need for federally mandated, across-the-board site design requirements. EPA's review of Subtitle D regulation presents an opportunity for USWAG to go beyond demonstrating that the industry's past practices were pretty good. Now we can show that the mans are at hand to design and construct disposal facilities that can meet any groundwater performance standard that EPA may promulgate as being protective of public health and the environment.

In the past, utility ash landfill design focused mainly on the operating needs of the producing plant and typical structural requirements,

such as dike and berm design. Very often state design standards for landfills were incorporated in order to obtain necessary permits and approvals. These state design standards were usually of an empirical nature, and were largely intended to reduce the flow of leachate from the ash to groundwater. Often, the same design standard was applied to municipal wastes and other industrial wastes, as well as coal ash. On the other hand, some states exercised little authority in coal ash disposal and imposed no groundwater protective requirements on utilities.

In recent years, many utility companies have begun to employ mathematical models to predict leachate migration from their ash disposal facilities in order to seek exceptions from state imposed standards or to satisfy themselves that their facilities were or would perform satisfactorily. These efforts constitute the beginnings of disposal site performance analysis, but there have been some very significant pieces missing which are necessary to make accurate predictions.

Several years ago, the Electric Power Research Institute (EPRI) canvassed utilities across the nation for their opinion on their most pressing need with respect to ash disposal issues. The utilities articulated their desires very clearly. They wanted the tools to analyze and predict the effects on groundwater of their ash disposal operations. EPRI responded by launching a multi-million dollar research program, which as its ultimate objective the development of techniques and programs desired by utilities, and basing these tools on through scientific research. Among the many facets of this research program, called Solid Waste Environmental Studies, are the development of leachate generation and groundwater transport codes, sampling techniques, the state of subsurface exploration methods, thorough understanding of the chemistry of leachates from ash in groundwater and, perhaps most importantly, a verification of the accuracy of all of the above. The research program is a massive one. We are not aware of any other research that delves more deeply into the analysis of solid waste disposal. So massive an undertaking cannot be completed overnight. At the present time, the five year old SWES program is expected to run well into the 1990's.

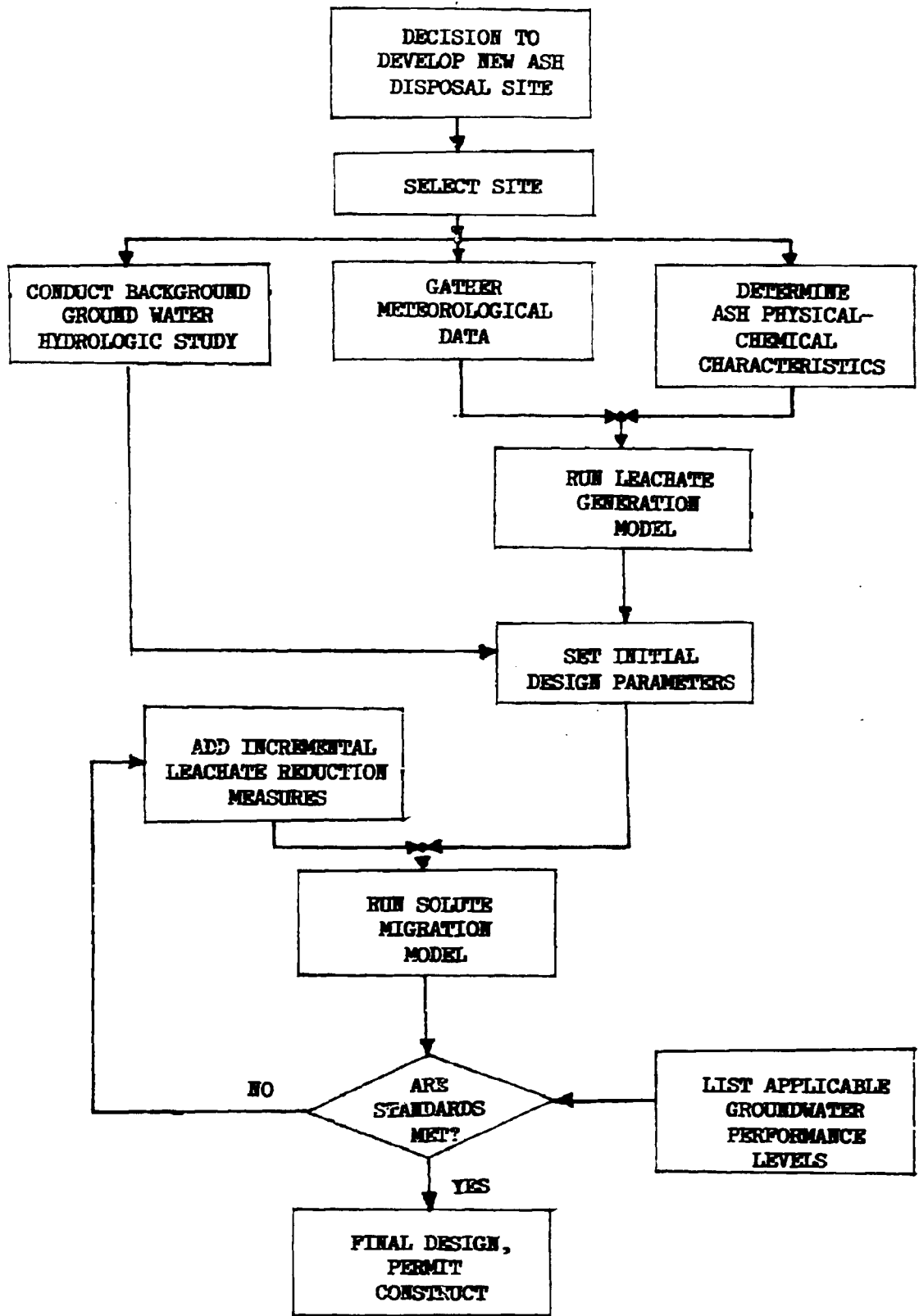
USWAG, while eagerly supporting EPRI's program, sees a window of opportunity opening up right now. Earlier I mentioned EPA's review of the RCRA Subtitle D nonhazardous regulatory program. EPA has requested suggestions on approaches to regulation of these wastes. The utilities have always held the position that ash disposal regulations ought to be based on the need to meet groundwater performance standards at some suitable receptor point. We believe EPA should set these standards and the utilities should be left to design facilities capable of meeting them, based on waste characteristics and site-specific conditions. The EPRI SWES program will provide the means to do this, but we felt that enough progress has been made to date to allow for sufficiently accurate prediction of landfill performance. With the help and advice of the SWES Program Manager, Dr. Ishwar Murarka, USWAG, has initiated a project to gather the best available components necessary for ash disposal site analysis and assemble them into a report that can be presented to EPA. The project will be completed in late

1987. The objective is to support the development of performance rather than design standards. It should be pointed out that this effort carries with it the assumption by USWAG that ash will be regulated as a nonhazardous waste. As discussed earlier, we cannot be absolutely certain this will be the case. EPA's report to Congress is still pending and the TCLP is undergoing further development. Still, all evidence at hand indicates that a nonhazardous status is the most likely for utility ash.

Figure I shows how the performance analysis process will work. There is nothing here that is surprising or novel. This approach is commonly used to solve engineering problems. One starts with basic site data such as rainfall runoff, subsurface and groundwater conditions. Based on the nature of the waste and available water for infiltration a prediction of the quality and quantity of leachate is made. A prediction is then made, using a groundwater transport code, as to the movement and quality of a leachate plume. The maximum concentration of regulated contaminants at the nearest feasible receptor point, which can be a well or surface water body, is compared with standards promulgated by EPA. If the standards are exceeded, one adds a leachate reduction measure, such as chemical waste fixing, or top cover or liners, and repeats the solution until standards are predicted to have been met.

USWAG's contractor will determine the best components currently available, will demonstrate their use on several hypothetical test cases and estimate the level of accuracy of the entire process. As new components that are more powerful or more accurate are developed, they can be substituted in the overall process.

In many respects, the fate of federal regulation of utility ash seems as uncertain as it did in 1976, when RCRA was first passed. It is true that no set of regulations have been proposed, nor has a decision been reached that federal regulation is even necessary. The matter of waste classification is not yet resolved either. 1988 may be the year in which these questions are resolved. The EPA report to Congress will be complete, EPA will propose rules as they think necessary shortly thereafter, and the Subtitle D program review will be well underway. Then too, 1988 is a reauthorization year for RCRA and Congress may use the opportunity to coax EPA to resolve some of the RCRA issues it has been dealing with for the last few years. The utility industry is in a much better position now than it was ten years ago in understanding the nature and potential environmental impacts of its wastes and should be able to respond strongly to any regulatory proposal or request for assistance from EPA. The result should be the most effective approach to safeguarding public health and the environment from any potential effects of utility ash disposal at the minimum cost.



CONCEPTUAL MODEL FOR USWAG FOSSIL FUEL RESIDUE DISPOSAL SITE PERFORMANCE PREDICTION PROCEDURE

FIGURE I

ABSTRACT

HMAC BOTTOM ASH OVERLAY IH 30 HOPKINS COUNTY

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I. Background

In 1980, District I began evaluating the use of bottom ash in hot mix asphaltic concrete pavements. Three test sections containing bottom ash were placed on Farm Market 1870, State Highway 11 and Interstate 30 in Hopkins County. The site locations were selected on the basis of various traffic conditions and existing surface conditions. The primary objective of this study was to determine the engineering properties and characteristics of the bottom ash and to determine the feasibility of utilizing a waste product in roadway construction.

After a five year study of the three test sections and an evaluation of both field and laboratory data, an overlay project on Interstate Highway 30 in Hopkins County was constructed.

II. Objective

The objective of this experimental project was to (1) evaluate the characteristics of bottom ash properties when incorporated into the ACP overlay surface and (2) evaluate the performance of the ACP when subjected to high volume traffic relating to internal and external structural properties of durability, stability, fatigue resistance, workability, tensile, cohesion, water susceptibility and surface skid data and (3) develop cost data for the completed construction.

III. Experimental Features

A 14.3 mile overlay over existing concrete pavement 38 feet wide was placed on both the east and west bound lanes. A total depth of 3 inches of HMAC was constructed with 2 inches of HMAC Type C base and one inch of HMAC Type D exposed to the surface. This construction project will be compared with an overlay project that was completed in March of 1985, on IH 30 in Franklin County from 0.27 miles east of Hopkins/Franklin County line to the Titus County line.

IV. Evaluation Process

Pre-construction test for physical properties of the mix and volumetric designs were performed by the District I Laboratory. There was no deviations from the standard design procedures required. Plant design data was analyzed before mixture placement on the roadway to insure compliance with the specifications. An annual condition survey of the total construction will be conducted and reported for a minimum of five years.

V. Test-Section Evaluation

A test section was constructed in the west bound outside lane from station 929+00 to 919+00. Three samples of mix were secured from the test section before compaction on 5-8-86. At station 929+00 the mix was secured from a location near the outside wheel path. Sample number 2 was secured from station 924+00 between the wheel path and sample number 3 from station 919+00 at a location near the inside wheel path. Samples were taken in this pattern to provide information on uniformity of the mix and to insure that the entire test section would be evaluated.

Attached to this report is a diagram of the test section showing locations where the road mix was secured and also the locations where field cores were taken.

Laboratory test results on the road mix and field cores are shown for each station located within the test section on the Cumulative Mechanical Analysis Charts along with the compaction data.

VI. Analysis of Data

Since placement of the test section on 5-8-86, the pavement has shown no signs of distress. Laboratory data from both the road mix and field cores indicate acceptable values and the air void content of the compacted pavement based on Test Method Tex. 227-F (Rice Method) are within acceptable limits.

Although the mix was somewhat tender and heat loss was rather rapid, adequate compaction was accomplished using a vibratory and pneumatic roller. A rolling pattern using a nuclear gauge was established. The base course bonded well with the concrete pavement and the C and D courses were also tightly bonded.

VII. Conclusion

The design and construction of bottom ash mixes are possible using the knowledge of modern HMA technology. An evaluation of this project during the next five years should give us a better insight into the reliability and future of the bottom ash mixes.

CHARACTERIZATION AND CLASSIFICATION OF LIGNITE
FLY ASHES FOR USE IN CONCRETE

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ABSTRACT

The USA and Canada have twenty-two lignite fired power plants with over fifty megawatts capacity. Four are in Canada, six in North Dakota, eight in Texas, and one each in Louisiana, Minnesota, Montana, and South Dakota. These plants do not all have available fly ash because of the particular flue gas desulfurization processes involved. About half of these plants are marketing fly ash for use in portland cement concrete. Some are disposing of all of the fly ash produced, either in landfills or back in the mine. The lignite fly ashes are from lignite mined from several different geologic formation. The Canadian lignite is from the Ravenscrag ((Paleocene) formation in Saskatchewan; the North Dakota lignite is mined from the Harmon, Hagel, and Beulah-Zap beds of the Fort Union (Paleocene) formation; and the Texas and Louisiana lignites are mined from three Eocene geologic units, the Wilcox and Jackson groups and the Yugua formation. The heating values of the lignites vary from 5,000 to 7,840 Btu/lb. as received, the ash content from 8 to 28.4 percent, and sulfur content from 0.6 to 1.67 percent.

Lignite fly ashes have higher CaO and MgO and lower SiO₂ than bituminous fly ashes. They also have a complex mineralogy and often includes several crystalline phases that participate in cementitious reactions (tricalcium aluminate, dicalcium silicate, and anhydrite) as well as free crystalline lime. Several chemically, physically, and mineralogically different lignite fly ashes have been used in portland cement concrete and produced similar results. Chemically, lignite fly ashes range as follows:

SiO ₂ :	25.7 - 60.2%
Al ₂ O ₃ :	10.7 - 24.5%
Fe ₂ O ₃ :	2.0 - 23.3%
SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃ :	44.9 - 84.0%
CaO:	5.4 - 26.8%
MgO:	1.1 - 7.6%
SO ₃ :	0.6 - 12.3%
Available Alkali:	0.4 - 5.3%

Physically, the fineness varies considerably, as well as the specific gravity and cement and lime pozzolanic activity indexes. There have been various studies to improve the reliability of predicting the performance of lignite fly ash in concrete, based on the pozzolanic activity index. Mineralogically,

x-ray diffraction is a valuable tool to explain the behavior of lignite fly ashes in concrete, with respect to strength and sulfate resistance. There are several specifications involving the use of fly ash as a partial replacement for portland cement in concrete, and they include: American Society for Testing and Materials, C-618; Canadian Standards Association CAN3 - A232.5 M295-86, several state departments of transportation, and several foreign countries.

The controversy between Class F (bituminous and anthracite) and Class C (lignite and subbituminous fly ashes) has been due in part to the wide variation of chemical, physical, and mineralogical properties of the lignite fly ashes. Many lignite fly ashes can meet the specification limits for Class F fly ash.

A summary will be presented of various investigations involving lignite fly ashes in concrete and mortars, and an attempt will be made to characterize and classify the North American lignite fly ashes, using mineralogical, chemical, and physical data. The geological variability of the lignite formations, as well as the varying power plant configurations will be addressed.

Poster Sessions .

Co-Chairmen: J. R. Jones, U.S. Department of Energy,
D. K. Rindt, University of North Dakota
Energy Research Center

POSTER SESSIONS

Co-Chairmen: Joanne R. Jones, U.S. Department of Energy, and Diane K. Rindt, University of North Dakota Energy Research Center

1. WET FUEL HANDLING - A PROGRAM TO MINIMIZE PLUGGAGE
Robert Bennett, William Fogel and Paul Aloia, GUS, Inc.
2. CLEAN, LOW-RANK COAL SLURRY FUELS
Raymond Dewall, University of North Dakota Energy Research Center
3. IN-SITU MINING OF LIGNITE WITH ALKALINE SOLUTIONS
P. E. Fischer, Hector A. Garza, Chen-Lun Liu, and Wen O. Ouyang, Texas Tech University
3. THE MEASUREMENT AND MODELING OF THERMAL PROPERTIES OF LIGNITE COALS
Greg C. Glatzmaier and W. Fred Ramirez, University of Colorado
4. FUNDAMENTAL STUDIES OF ASH FORMATION DURING THE COMBUSTION OF LOW RANK COAL
Frank T. Green and J. Eugene O'Donnell, Midwest Research Institute; George Montgomery, University of North Dakota Energy Research Center
6. CHARACTERIZATION AND CLASSIFICATION OF LIGNITE FLY ASHES FOR USE IN CONCRETE
Oscar E. Manz and Bruce Dockter, University of North Dakota; Gregory J. McCarthy and Dianne M. Jonansen, North Dakota State University
7. PILOT-SCALE EVALUATION OF FURNACE SORBENT INJECTION FOR SO₂ CONTROL FIRING CANADIAN LOW-RANK COALS
Bruce G. Miller and Greg F. Weber, University of North Dakota Energy Research Center
8. KINETIC MODEL DEVELOPMENT FOR LIGNITE LIQUEFACTION
P. K. Moore and R. G. Anthony, Texas A&M University
9. COLLOIDAL COAL CLEANING METHOD FOR LOW-RANK COALS
E. S. Olson, J. W. Diehl, and T. J. Malterer, University of North Dakota Energy Research Center
10. WILDLIFE HABITAT CONSIDERATIONS AND NATIVE GRASSLAND RECLAMATION AT THE JEWETT MINE, LEON CO., TEXAS
Mark Rhodes, Northwestern Resources Co.

WET FUEL HANDLING - A PROGRAM TO MINIMIZE PLUGGAGE

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ABSTRACT

Assuring the free flow of wet fuel through transfer points, hoppers and downcomers has been a problem for years. This is often more acute with strip-mined lignite where varying amounts of clay and dirt can be inadvertently mixed in with the fuel in the mining process. Often, a station is required to utilize whatever fuel is supplied, seldom having advanced knowledge of fuel quality or the option of fuel blending.

It has been proven that fuel can be enhanced significantly by application of certain surfactant or polymer formulations. Additionally, time has been shown to be effective in several applications. The current laboratory method of fuel flow evaluation involves a rotational shear tester to quantify fuel quality. This technique minimizes sample preparation and test time. This allows results to be obtained in time to anticipate fuel handling problems by testing in the field at the plant site.

While moisture content has a major impact on fuel flow, it has also been found that the finer mesh fractions of fuel contain greater percentages of silica than the bulk fuel. This indication of ash or clay is another parameter which can correlate with fuel pluggage. Extensive evaluation with a portable x-ray fluorescence analyzer has shown that this method can be used to monitor silica and ash on a real time basis.

The current on-site wet fuel monitoring program entails continuous monitoring with periodic evaluation of fuel for moisture content, silica content, and shear test values. An extensive base can be established for each site, relating fuel quality to pluggage problems and factors determined for the use of chemicals and the feed rates required.

By monitoring the fuel this closely, the number of pluggage incidents, their duration, the cost of chemical treatment, and lost generation can all be minimized.

CLEAN, LOW-RANK COAL SLURRY FUELS

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ABSTRACT

The majority of today's coal/water slurry technology has been developed to prepare high-energy liquid fuels from bituminous coals. In addition to this technology, a majority of the coal cleaning technology has been directed towards developing a clean, high-energy fuel from bituminous coal.

At the University of North Dakota Energy Research Center (UNDERC) advanced processes are being investigated for preparing clean coal and coal/water slurry fuels from low-rank coals. A process developed at UNDERC using hydrothermal treatment (HT) of coal has produced high-energy density fuels. In this process, the coal is treated at elevated temperature and pressure to remove the inherent moisture and modify the surface properties of the low-rank coals. Depending on the amount of moisture in the raw coal, the process allows the coal to be slurried in its own water.

By removing the inherent moisture of the coal, hydrothermal treatment allows highly concentrated coal/water fuels to be prepared from low-rank coals. This is complemented by incorporating comminution steps, to obtain an optimal coal particle size distribution in the coal/water fuel production scheme to further enhance coal concentration. Slurry fuels with up to 8000 Btu/pound have been prepared after HT from low-rank coals. Any further concentration and stabilization of the fuel required the use of additives. Research is continuing in all areas of HT fuel slurry enhancement.

Due to the limited cleaning data available to low-rank coal, there is a need for establishing a data base. To meet DOE's long-range goals, investigation of methods to clean the coal to less than 1.0% ash are also included. The preparation of clean (0.4% to 1.0% ash), high-energy density slurry fuels from low-rank coals has been accomplished using a combination of physical and chemical methods prior to HT. The physical methods presently used at UNDERC are froth flotation and heavy media washability.

Chemical cleaning using acid leaching has shown the most success as a second step, following physical cleaning, in the preparation of clean low-rank coal. In the acid leaching step the mineral matter is removed from the physically cleaned coal by mixing with dilute acid and filtering to recover the clean coal. The clean coal is then hydrothermally treated, and high-energy slurry fuels are prepared.

Coal/water fuels from low-rank coals can be produced by integrating the steps of physical cleaning, chemical cleaning, hydrothermal treatment, optimum sizing and proper additives in an advanced preparation process. These clean high solids content slurry fuels would then be suitable for use in residential furnaces and in advanced combustion systems.

IN-SITU MINING OF LIGNITE WITH ALKALINE SOLUTIONS

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ABSTRACT

The economical recovery of lignite from deep seams can be achieved using alkaline solutions as the extracting agents. There are several advantages of using these solutions like the low severity of the process, cheap solvent, high extraction yields, low pollution potential and easy separation of the solvent from the product by pH adjustment.

The process proposed will consist in the injection of a stream of sodium hydroxide or sodium carbonate into a deep seam, this solution will contact the lignite and extract it at a low to moderate temperature level. The extract will be pumped to the surface and contacted with carbon dioxide to precipitate the lignite, and the clear liquid will be recycled to the formation to continue the extraction process.

This paper will present the results for carbonate extraction of lignite, the study with sodium hydroxide can be found elsewhere¹. Two sets of experiments were performed, for the first set small particles of Texas lignite (400 grs), Wilcox formation were reacted with 500 ml of 0.5 and 0.25 normal solutions of sodium carbonate in a 2-liter batch reactor. The reaction times varied from 1 to 12 hours and were carried under an inert autogenous pressure. Temperature levels of 100, 130 and 160°C were used. Maximum conversion levels of 71% were found for these temperature-time levels, with higher conversion at the higher temperature level. Ionic strength do not have an appreciable effect on the final conversion levels. The maximum conversions were 5% at 100°C, and 30% at 130°C. The second set of experiments consisted on the reaction of these same mixtures at ambient temperature for periods up to 12 weeks with carbonate solutions of 0.1, 0.5 and 1.0N concentration. All of these experimental runs achieved a maximum extraction yield at 8 weeks, and then the soluble product decreased indicating the repolymerization of the extracted lignite into an insoluble form. The extraction yields for this experimental set were highly dependent upon ionic concentration, reporting 11% organic extraction with a 1.0N sodium carbonate solution, and 8% with a 0.1N solution.

The behavior of the kinetic data for this reaction system pointed to a two-step parallel mechanism. The reaction mechanism proposed consisted of a reaction step of lignite to solubles, and a competitive parallel step of lignite to insolubles. The activation energies found for the first step obey second order kinetics and are on the order of 20,000 kcal/mole and a frequency factor of 1×10^6 , for the second step first order kinetics was determined with the same activation energy, but a frequency factor of 1×10^{12} .

The results of this research validate the concept of using alkaline solutions for the in-situ mining of lignite, even at very low temperatures. The results indicate also the existence of a repolymerization step, that can

reduce yields. It is proposed that this step can be eliminated using dissolved oxygen in the alkaline solutions to control repolymerization and increase extraction yields.

The authors wish to thank Dow Chemical for their financial support.

1. Fischer, P.E., Ouyang Wen and Shah Rejiv, "Low Temperature Aqueous Alkaline Liquefaction of Texas Lignite," DOE/MTC-86/6036(Vol. 2), DE86001077, pp.421-434.

THE MEASUREMENT AND MODELING OF
THERMAL PROPERTIES OF LIGNITE COALS

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ABSTRACT

The thermal conductivity and thermal diffusivity of solid and powdered lignite coals were measured as a function of temperature and pressure using the transient hot wire method. The mathematical basis for the use of this method for measurement on solid materials is well understood and documented. Thermal property measurements on two-phase materials (powders) are more complex to analyze than those of solid materials. Heat transfer mechanisms in powders include conduction through the solid phase, conduction through the gas phase, along with heat transfer between the phases at any point in the material. Because of this complex means of heat transfer, thermal properties of powders are not true properties but are effective properties which account for all the heat transfer mechanisms. A mathematical model based on volume averaging was developed to predict measured values of the effective thermal properties of powdered materials. Modeling of the thermal properties included several powdered samples other than coal including glass beads and powdered oil shales. The model accurately predicted thermal properties of these samples which varied as a function of pressure over several orders of magnitude. This work provides an understanding of thermal property measurements of powders and of heat transfer mechanisms in general.

FUNDAMENTAL STUDIES OF ASH FORMATION DURING THE
COMBUSTION OF LOW RANK COAL*

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ABSTRACT

This research was undertaken to determine the behavior of alkali metal and other species implicated in ash fouling and slagging problems during low rank coal combustion. These studies are conducted in premixed laminar coal dust-air flames. Coordinated vapor phase, coal/ash and temperature measurements permit the determination of the behavior of the various species during the combustion process in both the vapor and condensed phases. The gaseous species were identified and their partial pressures measured as a function of distance along the flame axis using molecular beam mass spectrometry (MBMS). Coal/ash samples were collected as function of distance along the flame axis and analyzed by SEM/EDX, ESCA, and other techniques. Flame temperatures were measured using a thermocouple technique.

Profiles of a number of gaseous species have been obtained for lean pulverized Decker-N₂-O₂ and Beulah-N₂-O₂ flames. These flames had measured temperatures which ranged from about 1500°C just above the "reaction zone" to less than 800°C at large distances from the burner. For the alkali metals the only significant gaseous species observed to date are sodium and sodium hydroxide. Profiles of these two vapors indicate that a very large excess of Na(g) is produced early in the combustion of both Beulah and Decker, and that this excess is very short lived and decays either by reactions to form undetected gaseous sodium species or by conversion into a condensed phase. Downstream of the Na(g) "spike" the partial pressures of Na(g) and NaOH(g) are relatively constant. This is consistent with existing thermochemical data. Traces of Na₂SO₄ were also measured.

The particulates present at different positions in the Decker and Beulah flames were sampled using a free-jet technique and collected without the use of an interfering substrate. Analyses of the samples were carried out using ESCA. The resulting data indicate that part of the volatilized sodium is converted to a fume or other particulate form early in the combustion process, and that some of the sodium is collected on the ash particles.

* This work was supported by the U.S. Department of Energy, Grand Forks Project Office, under Contract No. DE-AC18-81FC10287.

CHARACTERIZATION AND CLASSIFICATION OF LIGNITE
FLY ASHES FOR USE IN CONCRETE

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ABSTRACT

The USA and Canada have twenty-two lignite fired power plants with over fifty megawatts capacity. Four are in Canada, six in North Dakota, eight in Texas, and one each in Louisiana, Minnesota, Montana, and South Dakota. These plants do not all have available fly ash because of the particular flue gas desulfurization processes involved. About half of these plants are marketing fly ash for use in portland cement concrete. Some are disposing of all of the fly ash produced, either in landfills or back in the mine. The lignite fly ashes are from lignite mined from several different geologic formation. The Canadian lignite is from the Ravenscrag ((Paleocene) formation in Saskatchewan; the North Dakota lignite is mined from the Harmon, Hagel, and Beulah-Zap beds of the Fort Union (Paleocene) formation; and the Texas and Louisiana lignites are mined from three Eocene geologic units, the Wilcox and Jackson groups and the Yugua formation. The heating values of the lignites vary from 5,000 to 7,840 Btu/lb. as received, the ash content from 8 to 28.4 percent, and sulfur content from 0.6 to 1.67 percent.

Lignite fly ashes have higher CaO and MgO and lower SiO₂ than bituminous fly ashes. They also have a complex mineralogy and often includes several crystalline phases that participate in cementitious reactions (tricalcium aluminate, dicalcium silicate, and anhydrite) as well as free crystalline lime. Several chemically, physically, and mineralogically different lignite fly ashes have been used in portland cement concrete and produced similar results. Chemically, lignite fly ashes range as follows:

SiO ₂ :	25.7 - 60.2%
Al ₂ O ₃ :	10.7 - 24.5%
Fe ₂ O ₃ :	2.0 - 23.3%
SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃ :	44.9 - 84.0%
CaO:	5.4 - 26.8%
MgO:	1.1 - 7.6%
SO ₃ :	0.6 - 12.3%
Available Alkali:	0.4 - 5.3%

Physically, the fineness varies considerably, as well as the specific gravity and cement and lime pozzolanic activity indexes. There have been various studies to improve the reliability of predicting the performance of lignite fly ash in concrete, based on the pozzolanic activity index. Mineralogically,

x-ray diffraction is a valuable tool to explain the behavior of lignite fly ashes in concrete, with respect to strength and sulfate resistance. There are several specifications involving the use of fly ash as a partial replacement for portland cement in concrete, and they include: American Society for Testing and Materials, C-618; Canadian Standards Association CAN3 - A232.5 M295-86, several state departments of transportation, and several foreign countries.

The controversy between Class F (bituminous and anthracite) and Class C (lignite and subbituminous fly ashes) has been due in part to the wide variation of chemical, physical, and mineralogical properties of the lignite fly ashes. Many lignite fly ashes can meet the specification limits for Class F fly ash.

A summary will be presented of various investigations involving lignite fly ashes in concrete and mortars, and an attempt will be made to characterize and classify the North American lignite fly ashes, using mineralogical, chemical, and physical data. The geological variability of the lignite formations, as well as the varying power plant configurations will be addressed.

**PILOT-SCALE EVALUATION OF FURNACE SORBENT INJECTION FOR
SO₂ CONTROL FIRING CANADIAN LOW-RANK COALS**

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ABSTRACT

During the period December 1984 through January 1986, the University of North Dakota Energy Research Center (UNDERC) conducted three series of tests to determine the effects of inherent and added alkali (furnace sorbent injection) on sulfur retention for lignite samples from four mines for Saskatchewan Power Corporation. The purpose of the study was to determine the potential for meeting a 0.60 lb SO₂ per million Btu (MM Btu) emission standard. A total of seven lignite samples were tested: 1) Boundry Dam Power Station - West Mine (one sample); 2) Boundry Dam Power Station - East Mine (one sample); 3) Poplar River Power Station Mine (three samples); and 4) Shand area - Costello Mine (two samples). The study included pilot-scale combustion tests of the coals in UNDERC's particulate test combustor (PTC). Sorbents used in the study included a Canadian limestone, an Iowa limestone, a high-calcium pressure hydrate prepared in the UNDERC bench-scale pressure hydrator, and two high-calcium hydrates produced in commercial facilities. Baseline tests with each fuel demonstrated that inherent alkali alone was not sufficient to meet the 0.60 lb SO₂/MM Btu emission standard even though SO₂ reduction values as high as 42% were observed. Furnace injection of the limestone was found to sufficiently capture SO₂ at a CaO/SO₂ mole ratio of 2.0 for three of the four coals tested. The 0.60 lb SO₂/MM Btu emission standard was met for all four test coals when a hydrate was injected at a CaO/SO₂ mole ratio of 0.7 to 2.2. All hydrates were injected into the PTC at a point where bulk flue gas temperature was 1825°F. Limestone was added to the coal feed venturi and entered the combustor through the burner. Utilization values for the hydrates and limestones ranged from 19% to 59% and 10% to 26%, respectively, for CaO/SO₂ mole ratios of 0.3 to 3.7.

INTRODUCTION

Coal is commonly used in Canadian thermal generating stations and therefore, techniques to reduce SO_x emission in coal firing are of primary concern. The sulfur content of Canadian coals varies from less than 0.4% in Western Canada to as high as 12% in Eastern Canada. The environmental implications of SO_x are that SO_3 , being highly reactive will react with water droplets creating a mist of sulfuric acid which eventually comes to earth as what is termed "acid rain". Sulfur dioxide (SO_2) can react within the ozone layer forming a more reactive species, SO_3 . Therefore SO_2 is considered a primary pollutant as is SO_3 (1).

The fact that Saskatchewan lignite sulfur dioxide emissions are already low due to the low sulfur content of the coal and the high capture by the inherent alkalis in the fuel has been the prime motivation behind the continued effort to develop a low capital cost method of sulfur dioxide control. Saskatchewan Power Corporation's (SPC) Boundary Dam Generating Stations emissions on many days already meet the Canadian Federal emission guidelines of 0.6 lbs of SO_2 per million Btu (MM Btu) energy input with no additional treatment required. The process of dry sorbent injection with staged combustion is seen as appropriate technology and, in fact, is the leading possibility for SO_2 control to be installed at the recently announced 300 MW Shand power station to be built by SPC in the Estevan area approximately seven miles from Boundary Dam (2).

The University of North Dakota Energy Research Center (UNDERC) examined the effects of inherent and added alkali (furnace sorbent injection) on sulfur retention for lignite samples from four mines for SPC. Pilot-scale combustion tests evaluated seven lignite samples to determine the potential for meeting a 0.60 lb SO_2 /MM Btu emission standard. The coals investigated included Boundary Dam West, Boundary Dam East, Poplar River, and Shand area-Costello lignites. Sorbents used in the study included a Canadian limestone, an Iowa limestone, a high-calcium pressure hydrate prepared in the UNDERC bench-scale pressure hydrator, two high-calcium hydrates produced in commercial facilities, and a high-calcium hydrate remaining from a field test at a power plant in Minnesota.

MATERIALS AND TECHNOLOGIES

Pilot-Scale Combustion System

The UNDERC Particulate Test Combustor (PTC) is a pilot-scale pulverized coal-fired combustor originally designed for particulate characterization and collectability studies. In addition, the PTC has other applications, such as the investigation of fireside additives for flue gas desulfurization. The refractory-lined combustor is 2 feet in diameter by 10 feet high and operates at a nominal heat input of 550,000 Btu/hr with either pulverized coal or natural gas. The combustor and corresponding ducting are designed for minimal particulate deposition before the collection device. Two particulate collection devices—a single wire tubular ESP and a three-mode baghouse (shaker, low-pressure expansion, and pulse) can be used for particulate studies.

Figure 1 presents a simplified schematic of the PTC. The coal nozzle is mounted on the bottom of the combustor. Coal is introduced to the primary air stream via a screw feeder and ejector. Secondary air is introduced concentric to the primary air with turbulent mixing. In addition, tertiary air is supplied above the base of the combustor. An electric air preheater is used for precise control of the combustion air temperature which is normally 750°F. Both forced draft (FD) and induced draft (ID) fans are used to supply combustion air and provide adequate flow control. Flue gas temperature control in the range of 200° to 800°F at the inlet to the particulate collection device is provided by water jacket cooling of flue pipes between the combustor and collector.

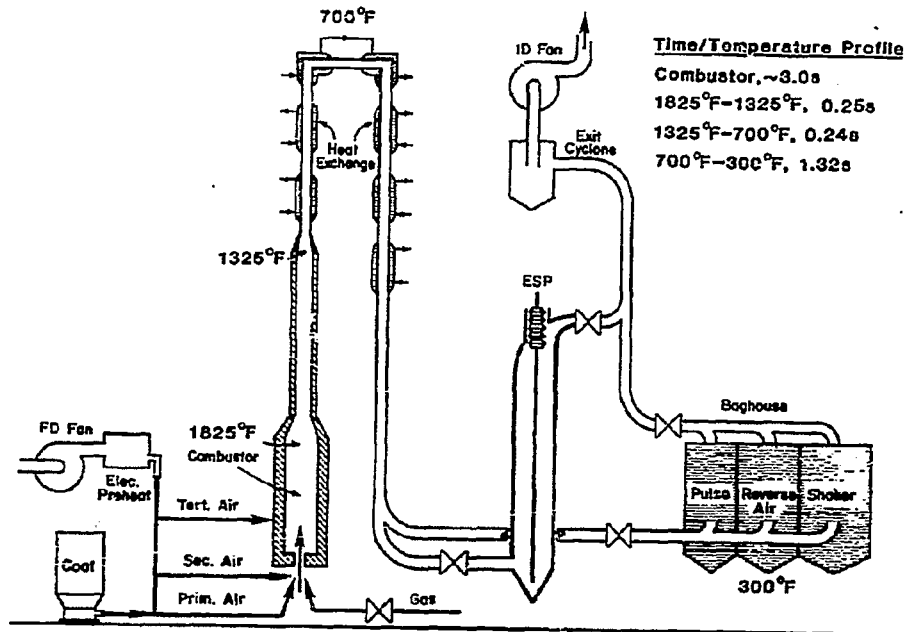


Figure 1. 550,000 Btu/hr Pc-Fired Test Combustor.

The combustor is oriented vertically to minimize wall deposits. The refractory lining helps to ensure adequate flame temperature for complete combustion and prevents rapid quenching of coalescing or condensing fly ash. The residence time of a particle in the combustor is approximately three seconds based on superficial velocity, but may be longer because of the intense turbulence in the flame region. This is greater than the maximum one second burn time required for 200 μ m or smaller coal particle. Combustion efficiencies are 99+% based upon loss on ignition of the fly ash and absence of CO in the flue gas.

Fly ash produced from the PTC is similar to fly ash from a full-scale pe-fired boiler. For most coals, microscopic examination of fly ash from the PTC reveals predominantly spherical particles; however, some coals produce particulates of several morphologies. Particles of PTC fly ash have mass median diameters in the 5 to 20 μm range. In cases where PTC generated fly ash has been compared to fly ash collected from a full-scale boiler burning the same coal, no major differences were identified.

Test Procedure

Seven combustion runs consisting of 41 two-hour test periods were conducted. The coals evaluated included Boundary Dam West (PTC-BDW-281), Boundary Dam East (PTC-BDE-282), Poplar River (PTC-PR-283, -291, and -304), and Shand area-Costello (PTC-C-284, and -290). The first two-hour test period for each combustion run generated baseline data with no added sorbent. The remaining 34 two-hour tests were alkali addition tests with stoichiometric ratios (stoichiometric ratios were originally based on sulfur in the coal) of approximately 1.0 or 2.0. Sorbents used in the study included a Canadian limestone, an Iowa limestone (Linwood limestone), a high-calcium pressure hydrate prepared in UNDERC's bench-scale pressure hydrator, two high calcium hydrates produced in commercial facilities (Western and Commercial hydrates), and a high-calcium hydrate remaining from a field test at Otter Tail Power Cooperative's Hoot Lake power plant.

Samples collected during the tests were taken from the coal and sorbent feeders. Surface area of the sorbents was measured using a single point monosorb surface area analyzer and crystalline phases were identified with x-ray diffraction. Spectrochemical analyses of the sorbents and coal ash were obtained by x-ray fluorescence. Proximate and ultimate analyses of the coal and ash fusion temperatures of the coal ash were determined. Details of the analytical procedures are available in previous publications (3,4).

Bench-Scale Pressure Hydrator

A batch pressure hydrator was designed and fabricated at UNDERC to produce up to 8 lbs of hydrate per run. A schematic of the unit is presented in Figure 2. The reaction vessel consists of an 8 inch diameter schedule 80 carbon steel pipe 12 inches in length, with carbon steel flanges capping both ends. A paddle-wheel stirrer is used to mix the lime and water thoroughly in the vessel, turning at a rate of 2 revolutions per minute. Pressurized water enters the hydrator through 1/8 inch nozzles affixed to the hollow stirrer shaft.

Approximately 6 lbs of quicklime (minus 140 mesh) are placed in the hydrator at the beginning of a run, and heated to 330°F. The solution storage tank is charged with 2.7 lbs of deionized water when high-calcium pressure-hydrated lime (PHL) is prepared. High-pressure air is used to pressurize the solution tank to 100 psig. When the reactor reaches the proper preheat temperature for a given set of conditions, hydration solution is carefully added under pressure. Excess water is used to ensure complete hydration of the lime and saturate the reactor with steam. Due to the exothermic reaction, the reactor temperature rises to about 370°F, and pressure is held constant at about 150 psig. As the hydration reaction is occurring, hydrator pressure is maintained constant by adding the hydration solution at a controlled rate.

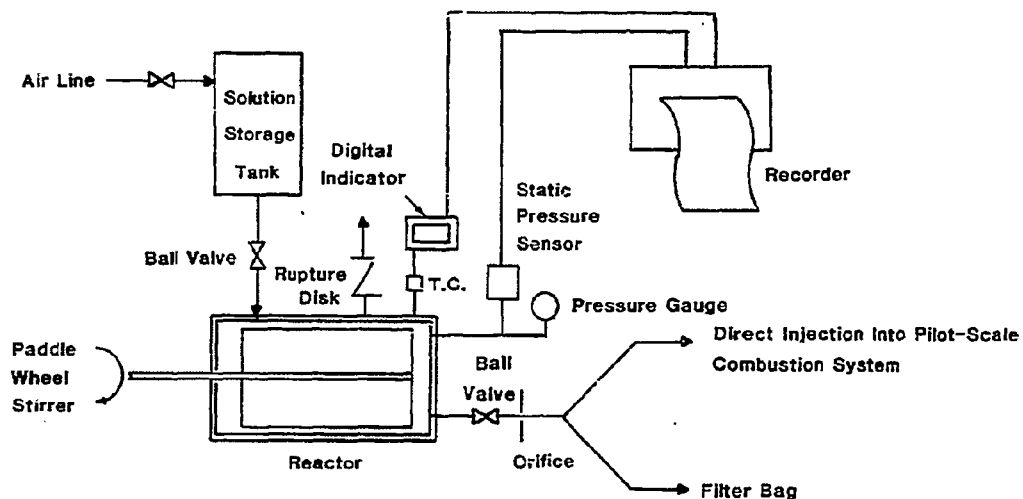


Figure 2. UNDERC Bench-Scale Pressure Hydrator.

After completion of the reaction and during hydrate expulsion, reactor pressure is maintained using a regulated source of nitrogen or compressed air. About 20 minutes after addition of solution to the vessel, the internal temperature begins to decrease, which indicates that the reaction is virtually complete. Hydrated lime is then flashed to ambient pressure through a ball valve. Upon expulsion of the hydrate/saturated steam mixture from the hydrator, water trapped inside the pore network of the hydrate particles is released explosively, yielding flash dried, submicron particles with a high external surface area. The particles are collected in a nylon fabric filter bag, and stored for subsequent furnace injection tests.

RESULTS AND DISCUSSION

Coal and Coal Ash Analysis

Complete proximate and ultimate analyses were performed on coal samples collected during each of the six two-hour tests from Runs PTC-BDW-281, -BDE-282, -PR-283, and -C-284. Average values for these tests are contained in Table 1. The analyses of composite coal samples collected during the entire run from Runs PTC-C-290, -PR-291, -S-303, and -PR-304 are also contained in Table 1. The Boundary Dam West and East coals were very similar with only minor differences. Boundary Dam West coal had slightly higher carbon content and lower sulfur and oxygen values. The heating value and carbon content of Poplar River coal was significantly lower than the other three coals (10-15%). The Costello coals had the highest heating values and carbon contents.

TABLE I
AS-FIRED COAL AND COAL ASH PROPERTIES

Run No: Coal:	281 BDW ^a	282 BDE ^b	283 PR ^c	284 G ^d	290 G	291 PR	304 PR
Proximate Analysis, %:							
Moisture	22.9	23.5	27.0	28.0	22.5	27.3	29.1
Ash	11.1	11.3	13.8	8.0	30.1	26.7	28.6
Volatile Matter	29.5	28.5	27.3	27.6	39.6	29.9	28.4
Fixed Carbon	36.5	36.8	32.0	36.5	7.8	16.1	13.9
Ultimate Analysis, %:							
Carbon	47.47	45.30	42.39	46.66	51.38	38.09	39.23
Hydrogen	5.51	5.54	5.58	5.97	5.69	5.49	5.84
Nitrogen	0.79	1.01	0.87	1.13	0.86	0.54	0.52
Sulfur	0.39	0.43	0.58	0.69	0.65	0.60	0.80
Oxygen	34.69	36.50	37.75	37.60	33.67	39.14	39.71
Ash	11.10	11.30	13.80	8.00	7.80	16.10	13.90
Higher Heating Value, Btu/lb	7961	7861	6844	7839	8516	6513	6476
Elemental Ash Analysis, %:							
SiO ₂	40.3	41.3	39.5	23.3	24.3	44.6	34.6
Al ₂ O ₃	20.3	20.0	22.2	15.2	14.4	21.7	22.0
Fe ₂ O ₃	3.6	4.0	4.6	5.9	5.4	4.4	6.9
TiO ₂	1.4	1.2	1.1	1.4	1.2	1.0	0.8
P ₂ O ₅	0.6	0.2	0.5	1.3	1.1	0.4	0.4
CaO	15.0	13.8	15.6	17.6	18.1	12.1	16.9
MgO	3.9	3.5	5.0	4.2	4.0	4.3	5.3
Na ₂ O	5.5	6.6	0.9	10.1	9.1	0.6	ND ^f
K ₂ O	0.7	0.4	1.4	0.4	ND	1.9	0.5
SO ₃	8.8	9.0	9.4	20.8	22.4	9.0	12.6
Ash Fusion Temperature, °F:							
Initial Deformation	2000	2030	2050	2050	1960	2300	2294
Softening	2020	2070	2220	2070	2140	2330	2340
Fluid	2160	2220	2310	2120	2260	2440	2447

^aBoundary Dam West
^bBoundary Dam East
^cPoplar River

^dCostello
^eNormalized
^fNot detected

The coal ash was analyzed for the concentration of mineral oxides and ash fusion temperatures and the results are presented in Table 1. As expected, the Boundary Dam West and East coal ashes were nearly identical with 14-15% CaO. The Poplar River coal ash was similar to the Boundary Dam coal ashes with the exception of less Na₂O, approximately 1.0% as compared to 5.5-6.6%. The Costello coal ash was noticeably different from the other ashes. The ash contained considerably less alumina and silica (probably reflecting lower amounts of clay minerals), and the largest concentration of CaO and Na₂O.

Sorbent Properties

Table 2 presents analytical data which characterize the sorbents used during the combustion tests. The surface area and CaO content of the limestones, Linwood and Canadian, were approximately 1.0-1.4 m²/g and 52-54% by weight, respectively. The hydrated lime surface areas ranged from 7.0 or 8.0 m²/g to 20.0 m²/g with the Hoot Lake hydrated lime exhibiting the largest surface area. The Hoot Lake hydrated lime received from the utility had been exposed to the elements and was wet and sticky and posed potential feeding problems with the small-scale hydrate feeder; therefore, the hydrate was dried overnight to evaporate surface moisture. A change in the physical characteristics was noted from the drying. The surface area decreased from 28.0 m²/g for the undried sorbent to 20.0 m²/g for the dried sorbent. Chemically the sorbents were similar with the CaO content of the bulk hydrate approximately 72% by weight. The UNDERC pressure-hydrated lime and the Commercial hydrate were 74% CaO by weight and the Western hydrated lime contained 67% CaO by weight with a small quantity of magnesium detected.

Sulfur Retention

Data on sulfur retention by the inherent alkali in the coal and sorbent addition is presented in Table 3 for the Boundary Dam West and East and the Costello coal tests. The inherent sulfur retention of the Boundary Dam coals ranged from 17% to 36% at inherent stoichiometric ratios ((Na₂O + CaO)/S in the coal) of 3.07 to 3.37. The inherent alkali utilization ranged from 6.0% to 12.3%. The 0.60 lb SO₂/MM Btu standard was not met with SO₂ retention by the inherent alkali in the coal ash.

Calculated theoretical SO₂ emissions ranged from 0.96 to 1.11 lb SO₂/MM Btu based on 3.0% O₂ in the flue gas. Observed emissions without sorbent injection ranged from 0.66 to 0.92 lb SO₂/MM Btu. The theoretical and observed emissions without sorbent addition from the Boundary Dam East coal tests were slightly greater than those observed for the Boundary Dam West coal due to a higher sulfur content and somewhat lower heating value. With sorbent injection, SO₂ emissions ranged from 0.35 to 0.75 lb SO₂/MM Btu. Data from Boundary Dam coal tests indicates that the 0.60 lb SO₂/MM Btu standard could be met with Linwood limestone, UNDERC pressure-hydrated lime, or Commercial hydrate injected at stoichiometric ratios (CaO/SO₂) of 1.75, 0.75, and 1.20, respectively. Percent SO₂ reduction as a function of CaO/SO₂ mole ratio is depicted in Figure 3. Correlations with limestone addition and hydrated lime injection are evident. Calcium utilization was better during the Boundary Dam East coal tests but it is unclear why the utilizations differed. The sulfur content was higher in the Boundary Dam East coal but the difference does not appear to be large enough to affect the kinetics of the sulfur capture (5).

TABLE 2
SORBENT PROPERTIES

Sorbent	Run	Surface Area (m ² /g)	Mass Medium Diameter (μm)	80% Less Than (μm)	CaO (%)
Linwood Limestone	BDW-281	1.22	6.7	11.8	54
	BDE-282	1.24	6.2	10.0	54
	PR-283	1.37	6.5	10.6	54
	C-284	1.10	6.6	10.1	54
	PR-304	0.96	6.6	11.4	54
Canadian Limestone	C-290	1.42	7.0	13.0	52
	PR-291	1.41	7.0	13.5	52
UNDERC Pressure- Hydrated Lime	BDW-281	8.09	3.7	8.1	74
	BDE-282	7.86	2.6	4.7	74
	PR-283	7.36	3.5	7.2	74
	C-284	4.61	3.5	8.4	74
	C-290	9.19	4.4	9.6	74
	PR-291	7.91	4.1	8.0	74
Commercial Hydrate	BDW-281	15.51	5.2	10.0	74
	BDE-282	15.70	5.0	8.7	74
	PR-283	15.85	5.6	9.8	74
	C-284	15.00	5.4	10.0	74
Western Hydrated Lime	PR-304	11.72	4.3	7.8	67
Hoot Lake Hydrated Lime	C-290	18.82	4.0	6.6	72
	PR-291	22.10	4.5	7.4	72
Hoot Lake Hydrated Lime	Undried	27.77	7.0	10.8	72
	Dried	20.00	4.2	7.0	72

TABLE 3

SULFUR RETENTION DATA FROM BOUNDARY DAH WEST AND EAST AND COSTELLO COAL TESTS

Run/Sorbent	Sulfur Dioxide Emissions ^a , lb SO ₂ /MM Btu			Stoichiometric Ratios		Sulfur Retention		Utilization	
	Theoretical	w/c ^b	v ^c	Inherent (Na ₂ O + CaO)/s ^d	Added CaO/SO ₂ ^e	Inherent	Added	Inherent	Added
BDW-281									
Baseline	0.96	0.73	-	3.24	-	23.9	-	-	-
Linwood Limestone	1.00	0.79	0.75	3.20	0.54	20.7	5.3	4	-
Linwood Limestone	0.97	0.77	0.58	3.37	2.03	20.3	24.7	5	9.8
UNDERC PHL ^f	0.96	0.66	0.45	3.19	1.22	30.7	32.3	6.0	12.2
UNDERC PHL	0.96	0.77	0.37	3.29	2.01	20.1	52.2	9.6	26.5
Commercial Hydrate	1.02	0.82	0.37	3.09	1.66	19.4	31.3	6.1	26.0
BDE-282									
Baseline	1.07	0.87	-	3.07	-	18.7	-	6.1	-
Linwood Limestone	1.07	0.75	0.63	3.12	1.07	29.6	16.5	9.5	15.4
Linwood Limestone	1.09	0.73	0.50	2.93	1.82	33.3	31.4	11.4	17.3
UNDERC PHL	1.11	0.87	0.54	2.92	0.89	21.7	37.2	7.4	41.8
UNDERC PHL	1.11	0.92	0.35	2.89	1.51	17.2	62.2	6.0	41.2
Commercial Hydrate	1.11	0.71	0.37	2.89	2.05	35.6	48.8	12.3	23.8
C-284									
Baseline	1.83	1.13	-	1.72	-	38.3	-	22.3	-
Linwood Limestone	1.74	0.94	0.80	1.77	0.59	46.3	14.8	26.2	25.1
Linwood Limestone	1.82	0.85	0.53	1.69	2.29	53.6	37.5	31.7	16.4
UNDERC PHL	1.67	0.82	0.49	1.83	1.17	50.9	40.8	27.8	34.9
UNDERC PHL	1.74	1.30	0.51	2.20	1.41	25.6	60.5	11.6	42.9
Commercial Hydrate	1.75	0.93	0.60	1.78	2.28	46.7	35.1	26.2	15.5
C-290									
Baseline	1.51	0.87	-	1.82	-	42.2	-	23.2	-
Canadian Limestone	1.51	0.87	0.60	1.82	1.56	42.2	31.1	23.2	19.9
UNDERC PHL	1.58	1.15	0.50	1.82	1.28	27.3	57.0	15.0	44.5
UNDERC PHL	1.51	0.90	0.14	1.82	3.74	40.3	84.8	22.1	22.6
Hoot Lake Hydrate	1.51	0.71	0.45	1.82	1.44	52.9	37.4	29.1	26.0

^aSO₂ concentrations are based on 3.0% O₂ in the flue gas

^bWithout sorbent added

^cWith sorbent added

^dSulfur in the coal

^eSulfur in the flue gas

^fPressure-hydrated lime

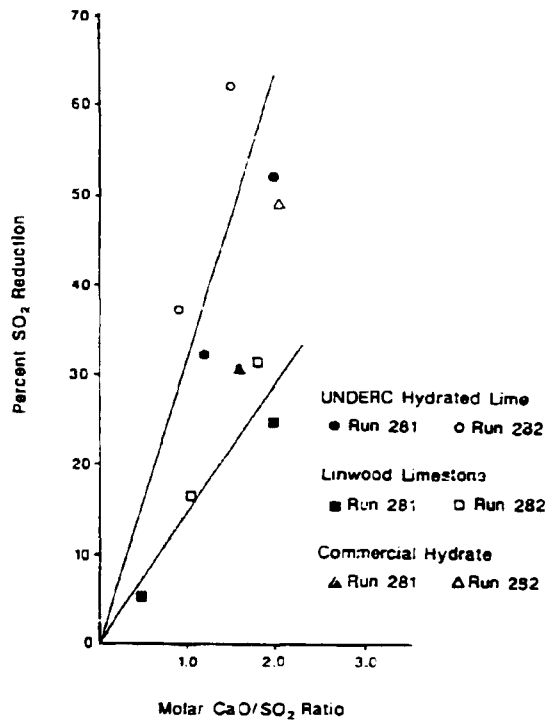


Figure 3. SO₂ Reduction During Boundary Dam West and East Coal Tests.

The Shand area-Costello coals exhibited the greatest amount of inherent sulfur capture which varied from 26% to 54% at an inherent (CaO + Na₂O)/S ratio of 1.8. The good sulfur capture was probably the result of the large concentration of Na₂O in the coal ash (~10%). The sodium reacts with sulfur and has been shown to have a positive effect on the calcium/sulfation reactions (5,6,7).

Calculated theoretical SO₂ emissions ranged from 1.51 to 1.83 lb SO₂/MM Btu while observed emissions without sorbent injection ranged from 0.71 to 1.30 lb SO₂/MM Btu. With sorbent addition, SO₂ emissions varied from 0.14 to 0.80 lb SO₂/MM Btu. A SO₂ emission rate of 0.60 lb SO₂/MM Btu could be met with Linwood limestone, Canadian limestone, UNDERC pressure-hydrated lime, Commercial hydrate, or Hoot Lake hydrated lime injected at approximate CaO/SO₂ mole ratios of 1.6, 1.6, 0.7, 2.0, and 1.0, respectively. Calcium utilizations ranged from 16% to 25% for the limestones and from 16% to 45% for the hydrates.

Figure 4 illustrates the relationship between percent of SO₂ reduction and the injected CaO/SO₂ mole ratio for the Costello coal tests. The UNDERC pressure-hydrated lime injection tests showed a strong correlation and is consistent with tests performed at UNDERC burning a North Dakota lignite (8). A strong correlation is also observed with the Linwood and Canadian limestones. This agrees reasonably well with results of Linwood limestone injection tests during combustion of Panola County, Texas lignite (9).

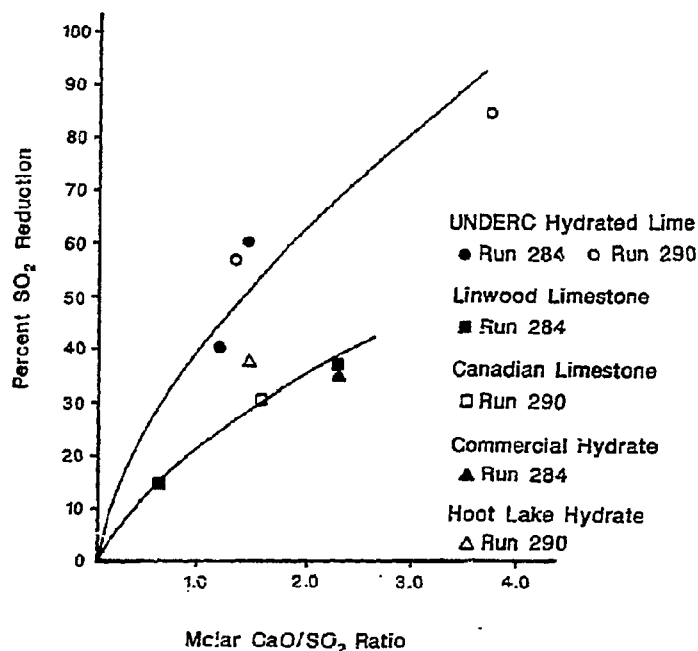


Figure 4. SO₂ Reduction During Shand Area-Costello Coal Tests.

Data on sulfur capture by the inherent alkali in the coal and sorbent addition is presented in Table 4 for the Poplar River coal tests. The inherent sulfur capture of the Poplar River lignite was 10% to 23% at inherent CaO/S moles ratios of 1.7 to 2.4. This was the lowest level of inherent sulfur capture noted for the entire test program and probably resulted from the low Na₂O content of the coal ash (<1.0%).

The theoretical and observed SO₂ emissions without sorbent addition ranged from 1.63 to 2.48 lb SO₂/MM Btu and from 1.40 to 2.24 lb SO₂/MM Btu, respectively. The SO₂ emissions with sorbent addition ranged from 0.53 to 1.87 lb SO₂/MM Btu. Data from the Poplar River coal tests indicates that the 0.60 lb SO₂/MM Btu standard may be difficult to meet with a reasonable quantity of limestone addition (CaO/SO₂ mole ratio \leq 3.0). The standard could be met with UNDERC pressure-hydrated lime, Commercial hydrate, or Western hydrated lime injected at CaO/SO₂ mole ratios of 1.8. The Hoot Lake hydrated lime should also sufficiently lower SO₂ emissions to meet the 0.60 lb SO₂/MM Btu standard even though the results do not indicate this. The SO₂ reduction results from the Hoot Lake Hydrated lime injection tests at CaO/SO₂ mole ratios of 0.9 and 1.3 were identical, resulting in a larger decrease in sorbent utilization with increasing CaO/SO₂ mole ratio than would be expected.

TABLE 4

SULFUR RETENTION DATA FROM POPLAR RIVER COAL TESTS

Run/Sorbent	Sulfur Dioxide Emissions ^a , lb SO ₂ /MM Btu			Stoichiometric Ratios		Sulfur Retention		Utilization	
	Theoretical	w/o ^b	w ^c	Inherent (Na ₂ O + CaO)/S ^d	Added CaO/SO ₂ ^e	Inherent	Added	Inherent	Added
PR-28J									
Baseline	1.71	1.44	-	2.14	-	15.8	-	7.4	-
Linwood Limestone	1.67	1.43	1.21	2.27	0.75	14.2	15.7	6.3	20.9
Linwood Limestone	1.63	1.42	1.02	2.38	1.64	13.0	28.0	5.5	17.1
UNDERC PHL	1.55	1.44	0.87	2.24	0.82	11.5	39.8	5.1	48.5
UNDERC PHL	1.74	1.40	0.53	2.14	1.87	19.7	61.9	9.2	33.1
Commercial Hydrate	1.79	1.51	0.83	2.11	1.56	15.8	44.9	7.5	28.8
PR-29I									
Baseline	1.84	1.53	-	1.93	-	16.9	-	8.8	-
Canadian Limestone	1.84	1.53	1.23	1.93	0.77	16.9	20.1	8.8	26.1
UNDERC PHL	1.85	1.43	1.01	1.93	0.64	23.0	29.1	11.0	45.5
UNDERC PHL	1.85	1.59	0.59	1.93	1.61	14.3	63.2	7.4	39.3
Hoot Lake Hydrate	1.85	1.44	0.97	1.93	0.91	22.2	32.5	11.5	35.7
Hoot Lake Hydrate	1.86	1.42	0.96	1.93	1.32	23.4	32.3	12.1	24.5
PR-304									
Baseline	2.47	2.09	-	1.68	-	15.5	-	9.3	-
Linwood Limestone	2.47	2.14	1.84	1.68	0.59	13.4	14.1	8.0	13.6
UNDERC PHL	2.48	2.10	1.64	1.68	0.22	15.4	21.6	9.2	98.2
UNDERC PHL	2.47	2.09	1.02	1.68	1.12	15.3	41.3	9.1	45.8
Western Hydrate	2.48	2.24	1.87	1.68	0.28	9.7	16.6	5.8	59.2
Western Hydrate	2.48	2.04	1.24	1.68	0.95	17.8	39.1	10.6	41.2

^aSO₂ Concentrations are based on
3.0% O₂ in the flue gas.
^bWithout sorbent added
^cWith sorbent added

^dSulfur in the coal
^eSulfur in the flue gas
^fPressure-hydrated lime

The Hoot Lake hydrated lime injection test at a CaO/SO_2 mole ratio of 0.9 is consistent with field tests conducted at the Hoot Lake power plant (10). Therefore, the sorbent used during the test conducted at a CaO/SO_2 mole ratio of 1.3 may have been of poor quality.

Figure 5 shows the relationship between the percentage of SO_2 reduction and the injected CaO/SO_2 mole ratio during the Poplar River coal tests. Strong correlations are noted with the hydrated limes (UNDERC and Western) and the limestones (Linwood and Canadian).

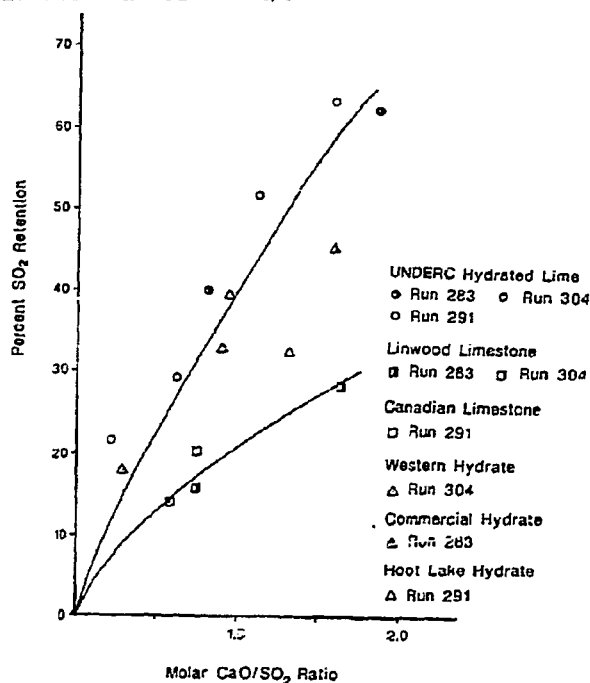


Figure 5. SO_2 Reduction During Poplar River and Shand Coal Tests.

CONCLUSIONS

Seven pilot-scale combustion tests were conducted to investigate the effects of inherent and added alkali on sulfur retention. The coals examined on UNDERC's particulate test combustor include Boundary Dam West and East, Poplar River, and Shand area-Costello. Based on these combustion tests, inherent sulfur capture alone will not meet the 0.60 lb $\text{SO}_2/\text{MM Btu}$ standard for any of the coals.

Conclusions resulting from the Boundary Dam West and East coal tests include the following:

1. The 0.60 lb SO₂/MM Btu standard could be met with either limestone or hydrated lime injection. The standard could be met injecting Linwood limestone, UNDERC pressure-hydrated lime, or Commercial hydrated lime at CaO/SO₂ mole ratios of 1.75, 0.75, and 1.20, respectively.
2. The lowest SO₂ emission rates were observed during UNDERC pressure-hydrated lime injection.

The results from the Shand area-Costello coal tests are:

1. The injection of UNDERC pressure-hydrated lime resulted in the lowest SO₂ emission rate.
2. The 0.60 lb SO₂/MM Btu emission rate could be met with limestone, UNDERC pressure-hydrated lime, Commercial hydrate, or Hoot Lake hydrate injected at CaO/SO₂ ratios of 1.6, 0.7, 2.0, and 1.0, respectively.

The Poplar River coal tests yielded the following results:

1. The 0.60 lb SO₂/MM Btu standard was met only with UNDERC pressure-hydrated lime.
2. The standard could not be met with a reasonable quantity of limestone (CaO/SO₂ mole ratio \leq 3.0) but could be met with hydrated lime (UNDERC, Commercial, Western, and Hoot Lake) injected at a CaO/SO₂ mole ratio of 1.6.

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KINETIC MODEL DEVELOPMENT FOR LIGNITE LIQUEFACTION

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ABSTRACT

The development of coal liquefaction technology has been hindered by the lack of a suitable kinetic model. The kinetic models currently in use depend upon simplified analytical methods, such as solubility or volatility analysis, to describe the coal liquefaction products. These models are empirical and apply only to the particular coal for which they were developed. A kinetic model capable of describing the liquefaction of a variety of coal types represents a significant contribution to the current technology.

The development of an improved kinetic model for coal liquefaction requires the utilization of a more advanced analytical technique than lumped solubility or volatility analyses. Such a technique has been developed using Size-Exclusion Chromatography (SEC), Gas-Liquid Chromatography (GC), and Mass Spectrometry (MS). SEC is used to separate, based on differences in molecular size and compound type, the coal liquid sample into several fractions, which are then analyzed by GC-MS. Thus, the SEC-GC-MS analytical technique provides molecular size, volatility, and mass-spectral information about each coal liquid component.

The SEC-GC-MS technique has been used to analyze data from liquefaction experiments performed using tubing bomb microreactors and several lignites. The results of these analyses have been utilized in the development of a general liquefaction model, which incorporates a continuous liquefaction model, which incorporates a continuous lumping scheme. The continuous lumping method allows the SEC and GC chromatograms to be used directly and enables a maximum amount of data to be represented with a minimum number of parameters. The lumping system is based on a component identification system utilizing the SEC and GC retention times as indices. These indices correspond to actual physical components, which remain the same regardless of the coal being liquefied; hence, the effect of the coal type upon the kinetic model is minimized.

The liquefaction kinetic model has been based upon the individual liquid and vapor phase compositions instead of upon the overall reactor composition. The liquid and vapor phase compositions were obtained from equation-of-state vapor-liquid equilibrium (VLE) calculations, used in conjunction with the continuous lumping method. The use of equation-of-state (VLE) calculations enables the kinetic model to account for differences in the volatility of the reactants and provides a means by which the (VLE) behavior of the liquefaction reaction may be optimized.

The total combined system, consisting of a tubing-bomb reactor model, a vapor-liquid equilibrium model, the continuously-lumped kinetic model, and a parameter estimation routine, provides a means by which all of the operating parameters in coal liquefaction may be optimized. In addition, the techniques

which have been developed will be useful in other petrochemical applications, such as refining and polymer processing.

COLLOIDAL COAL CLEANING METHOD FOR LOW-RANK COALS

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ABSTRACT

A new coal cleaning process, called the colloidal coal cleaning (CCC) method, has recently been discovered for low-rank coals (LRC) at the University of North Dakota Energy Research Center (UNDERC). The CCC method converts raw LRCs into a low-ash humate, in a stable aqueous dispersion (latex) which can be acid precipitated. Because LRCs contain abundant carboxylic acid and hydroxyl groups, they are hydrophilic and yield significantly high amounts of humate when treated with aqueous bases. Base treatment and high speed blending are key elements in the method.

In the CCC method, coal samples (10 g) were blended with 5% NaOH solution or other basic solution (250 ml) in a 1.25 L kitchen-style Osterizer under N₂ atmosphere. Temperature rose to about 45°C during blending. Blender speed (high, 24,000 rpm; medium, 18,000 rpm) and time (2 to 12 hrs) were varied in the experiments. The blended slurry was washed into 250 ml centrifuge bottles and centrifuged at 3000 rpm. The supernatant latex (humate) was decanted from the residue. Addition of acid to the latex resulted in precipitation of the humate.

Conversions were determined from weight yields of the precipitated humate after drying. Using 5% NaOH, a Beulah (ND) lignite (11.7% mf ash, 2.8% s contents) had highest conversions (90%) at high blender speed and low conversions (28%) at medium speed. The ash content in the 90% yield was only 0.83% (0.75% S) and in the residue the ash content was 19.0% (0.73% S), indicating successful removal of most mineral matter. The residue (unconverted coal) was examined by photoacoustic FTIR spectroscopy and microscopic petrographic techniques and was found to consist of minerals and liptinite macerals. At high blender speed, using Beulah lignite, a variety of other bases (Na₂CO₃, NH₄OH, pyridine, NaOCH₃) produced low conversions, 27%, 11%, 7%, and 3% respectively. High conversions of subbituminous coals were also obtained using NaOH and high blender speed.

Although our bench-scale investigations are preliminary, the results are particularly encouraging, and may suggest that many LRCs may be suitable for this type of cleaning technique. Utilization of the cleaned, precipitated humate can be used directly as an extrudate (pellets, briquettes). Also, preparation of cleaned humate as a slurry is being investigated.

WILDLIFE HABITAT CONSIDERATIONS AND NATIVE GRASSLAND
RECLAMATION AT THE JEWETT MINE, LEON CO., TEXAS

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ABSTRACT

The Jewett Mine is located approximately halfway between Dallas and Houston in East Central Texas. The mine is within the Post Oak Savannah economic region receiving approximately 40" of rain/year.

The mine produces over 7 MTPY disturbing an average of 500 acres/year with three 72 yd class draglines and a sizeable scraper fleet. Regraded spoil has demonstrated plant growth characteristics superior to the native topsoil eliminating the need to salvage topsoil.

The pre-mine land uses of the area were mainly comprised of improved pasture containing coastal bermuda grass (*Cynodon Dactylon*) or grazing land dominated by second growth oak-hickory (*Quercus* spp., *Carya* spp.) woodland. Under OSM definitions the oak-hickory woodland was considered grazing land because cattle occasionally t

these lands, but functionally these woodlands were the backbone of the wildlife habitat of the area.

The post-mine land use was planned to be compatible with the pre-mine land uses. A multiple use concept was used in planning the post-mine use resulting in a plan that provided for 50% native pasture, 25% improved pasture and 25% wildlife habitat. The native pasture would be comprised of improved varieties of native grasses. The improved pasture would be composed of coastal bermuda grass and the wildlife habitat would contain various shrub species, oak spp. and native grasses.

Large percentages of the post-mine area were chosen to be planted to native pasture to increase diversity of reclaimed area vegetation, lower maintenance requirements, and increase wildlife values. Methods of native grass establishment, species used and cost of establishment are discussed in relationship to its productivity and are compared to coastal bermuda grass establishment and productivity.

Wildlife habitat is to be established at 25% of the post-mine land use because of the value of the pre-mine wildlife habitat, aesthetics and potential economic return from hunting leases.

Wildlife habitat establishment on reclaimed lands is discussed in terms of problems which are both common and uncommon to pastureland reclamation. Common problems include proper erosion control, timing and cost. Problems not common to pastureland reclamation include, wildlife species habitat requirements, selection of proper plant materials, acquisition of proper plant materials, proper placement of wildlife habitat in relation to unmined areas

and other post-mine land uses and suitable tree and shrub placement, and spacing within the wildlife habitat areas.

Target species habitat requirements and planting methods to establish the necessary habitat are discussed. In conclusion, the costs and benefits of wildlife habitat reclamation are discussed in relation to other post-mine land uses.

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