Physical And Chemical Characteristics Of Coal Prep Plant Wastes From Southwest Virginia[1]

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Abstract. Coal prep plant wastes are difficult to reclaim due to high potential acidity and coarse fragment content, low water holding capacity, low fertility, and other problems. Little is known about their properties, particularly as they relate to revegetation potential. This study was undertaken to determine the physical and chemical properties of composite samples from 27 coal waste piles of varying age. Selected physical and chemical properties varied widely across this sample set. The pH values varied from 8.3 to 3.0, and the older piles had lower pH values than the more recent piles. Base saturations ranged from 100% to 1% and, as expected, were highly correlated with pH values. The saturated paste electrical conductivity (EC) was higher in the younger coal waste materials. The mean coarse fragment (>2mm) content of these materials was 60%. The average texture of the fine (<2mm) fraction was a sandy loam with 15% clay. The mean water retention difference, between 10.0 J kg^{-1} and 1500 J kg^{-1} of soil moisture tension, in the fine fraction was 0.136 g water/g soil. These moisture retention values are very low when compared with those of natural soils, particularly in light of the wastes' high coarse fragment content. Double acid extractable P was generally low, but a few samples had high levels of P. Our results indicate that some low-S refuse materials would be suitable for direct seeding, but serious water holding and long term nutrient availability problems are likely.

Additional Key Words: Coal refuse, reclamation, Appalachian coal fields.

Introduction

Thousands of ha of coal prep plant wastes (aka coal refuse, gob, slate,) occur in the eastern United States and with each ton of coal processed this figure increases. In Virginia alone, there are over 4,000 ha of permitted coal refuse disposal areas. The exact area of abandoned coal refuse piles is not well documented but is considerable. Virginia alone has spent over $7 million on the stabilization and reclamation of abandoned coal refuse piles. This is above and

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beyond what private coal companies have spent to reclaim active refuse disposal areas, as required by the Surface Mining Control and Reclamation Act of 1977 (SMCRA). One hundred and thirty-five million tons of coal refuse were produced in the United States in 1983. Of this total 79% was coarse (> 0.5 mm) refuse (Khan et al, 1986) which was the subject of this study.

Improperly reclaimed coal refuse piles pose an ominous threat to the quality of the surrounding environment through slope failures, surface erosion, and the production of acidic leachates. These materials are difficult to reclaim due to physical problems, high levels of potential acidity, high soluble salt levels, low concentrations of plant nutrients, low water holding capacity, and high summer heat levels. Current regulatory policies require the use of a thick topsoil (1m) cover to reclaim active refuse disposal areas. This is an expensive and frequently impractical alternative in the Appalachian coal fields. Direct seeding of refuse is allowed only when long-term monitored trials indicate a high probability of reclamation success. Little comprehensive research has been conducted which would allow reclamationists to base restoration strategies on actual waste properties and conditions. There have been few studies in which the refuse properties were carefully evaluated, and then used to design replicated trials to evaluate the performance of different treatments.

The goal of this study has been to characterize the physical and chemical properties of coal refuse and then to relate important properties to reclamation potential. There have been a few studies which characterized coal refuse properties (Bland et al, 1977; Buttermore et al, 1978), but they did so from a total elemental, reprocessing standpoint. These studies do provide useful data on the range of refuse properties; however, they make no mention of reclamation potential.

Coal refuse will obviously share many characteristics with the associated coal seams. Mining, coal cleaning, and weathering processes also influence the properties of refuse. Criteria for the classification of mine soils were developed by Sencindiver (1977) and used to classify refuse soils by Delp (1975). In a study of 26 mine soils developed in coal refuse, Delp observed that the majority of surface horizons were topped with coarse fragments, local pockets of differing materials were common, and that rooting depth was dependent on soil pH. Buttermore and others (1978) analyzed coal refuse from seven mining districts in the eastern and midwestern United States, and observed that there was more variability within mining districts than between different mining districts. They also concluded that mining and cleaning methods (rather than geology) had the greatest influence on the elemental composition of coal refuse. We were unable to find a study in which the chemical properties of coal waste were evaluated using soil testing procedures, and then related to reclamation potential.

Materials and Methods

Sampled refuse piles were selected on the basis of coal seam, age of the pile, accessibility, coal company cooperation, and other factors. At least eight of the major coal producing seams of southwest Virginia were included in this sample set. Twenty-seven coal waste piles were sampled during the summers of 1986 and 1987. Large bulk samples (usually about 4kg) were obtained by combining several subsamples from each sampling site. The subsamples were taken at random across the walkable surface of each pile. On the larger piles one or two different representative areas were sampled. Erosional gullies, burned areas, toeslope positions, disturbed areas, and other nonrepresentative features were avoided during sampling. When possible, stable, noneroded positions were chosen for sampling. All samples were taken from the upper 10 cm of refuse. All coarse fragments larger than 15 cm were excluded at the time of collection. In addition to the refuse sample, information on the slope, aspect, age, and seam composition was recorded at each site. After collection, the bulk samples of refuse were taken to the laboratory for preparation and analysis.

All samples were air dried, sieved, and the percentage retained on a 2mm sieve recorded. A subsample of the coarse fragments (> 2mm) was retained for future analysis. The entire < 2mm fraction was retained for detailed analyses. Moisture desorption determinations at 10, 33, 100, 300, and 1500 J/kg soil moisture tension were performed on the < 2mm fraction of each sample using porous ceramic plates and pressure vessels. Refuse samples were placed in metal rings on the ceramic plates and were allowed to saturate by the procedure described by Richards (1965). Since most coal refuse shows limited development of soil structure, sample disturbance errors should be minimal. The soil moisture retention at each tension was then adjusted to reflect the entire refuse sample including coarse fragments. Particle size analysis by the hydrometer method of Day (1965) was performed on all samples. Weight loss at 923K, an estimator of carbon content, was determined by heating 5g of coal refuse for 3hr in a muffle furnace.

Soil pH was determined in a 1:1 soil:water slurry with a combination glass-calomel electrode and a pH meter (McLean, 1982). Electrical conductivities were determined from a saturated paste extract using a conductivity cell referenced to standard 0.01 N KCl (Rhoades, 1982). Extractable Ca, Mg, and K were determined by atomic absorbance spectrophotometry (AAS) after extraction with N NH_4OAc buffered at pH 7 (Thomas, 1982). Extractable Al was extracted with N KCl (Barnhisel and Bertsch, 1982). Cation exchange capacity was estimated by the summation of the extractable cations (Ca+Mg+K+Al) (Chapman, 1965). Percent base saturation was determined by dividing the sum of the basic cations by the total CEC.

Available P was extracted using a double acid solution, (0.05N HCl and 0.025N H_2SO_4), with subsequent colorimetric analysis as described by Olsen and Dean, 1965. Sodium dithionite-citrate-bicarbonate (DCB) was used to extract free-Fe (Holmgren, 1967) which was then determined using AAS. Total-Fe was determined using ion coupled plasma emission spectroscopy (ICPES) from a total digest using HF in a pressure bomb (Bernas, 1968) Total-S was determined using a LECO furnace S-analyzer.

Results and Discussion

For the purpose of limiting table size, six representative refuse materials were selected to illustrate the range of properties that are displayed by the 27 pile sample set for the tested parameters. The sample set mean is also presented for each parameter tested. These 6 samples represent 3 different ages of coal refuse. Locations MRP and KRP represent refuse that is approximately 60 years old, while locations PTH and RRP represent 30 year old material, and locations BMR and RRA represent active refuse disposal areas. The exact ages and the seam composition of each pile are given in Table 1.

The results of the sieve analysis and the particle size analysis on the <2mm fraction are presented in Table 2. The sample set mean of 59% >2mm is similar to the coarse fragment content reported by Buttermore et al. (1978) and Delp (1975) for refuse piles in this region. The majority of these materials had a sandy loam texture (<2mm), with a few being loamy sands and loams.

The coarse textured nature of these materials results in their having very low water holding capacities. This problem is compounded by the hydrophobicity of the carbonaceous surfaces in these materials. The relationship between soil moisture tension and water content for the six selected materials is shown in Figure 1. Site BMR has an exceedingly low water holding capacity. It is generated by a cleaning process in which the fines are removed and not recombined with the coarser material after processing. Recombination of some fines with the coarse at such sites would result in a particle size distribution with a higher water holding capacity.

Obviously, these materials will pose severe drought stress problems if left unamended. This drought stress would be most pronounced on south facing slopes, and on narrow flat tops of refuse piles. This large potential for drought stress underscores the need for amendments which raise the water holding capacity of these materials. Mulch and topsoil covers would bring immediate improvement in water holding capacity. Cover crops would shade the surface and provide mulch, which would facilitate the establishment of other species of plants, especially legumes. Physical weathering with time will also reduce the particle size of these materials which will in turn improve water holding. Any measure taken to improve the amount of available water in these materials will markedly improve the probability of reclamation success.

The percent weight loss of these materials at 923k is also presented in table 2.

Table 1. Pile ages, and major seams for six selected refuse sites.

Location	age	seams in pile
MRP	1930's	Pochahantas
KRP	1927	Wilson
PTH	1954	Imboden
RRP	1953	Imboden
BMR	active	Dorchester,Imboden,Parsons
RRA	active	75% Dorchester + Norton 25% Clintwood

Table 2. Percent coarse fragments (>2mm), percent fine fraction, particle size analysis, and weight loss at 923K of six selected sites and the 27 pile sample set mean.

Sample	% >2mm	% <2mm	% Sand	% Silt	% Clay	% Wt. loss
MRP	40	60	77.0	0.2	22.8	43.4
KRP	65	35	44.3	20.4	35.3	28.0
PTH	66	34	75.9	15.7	8.4	62.6
RRP	45	55	65.4	25.2	9.4	53.8
BMR	66	66	78.0	13.5	8.5	36.9
RRA	56	44	53.6	26.7	19.7	30.8
Mean$^{(n=27)}$	59	41	61.8	22.5	15.6	32.4

This parameter is being used as an estimate of the amount of carbon or coal present in these samples. There may be errors due to de-hydroxylation of the 1:1 clay minerals and weight losses due to carbonates, but this parameter does provide a rough estimate of the carbon content. A trend of increasing coal cleaning efficiency with time can be seen in these data.

Soil pH is probably the most commonly tested soil chemical parameter. The pH of a material directly influences the availability of many plant macro- and micro-nutrients. The mean pH value for the sample set was 4.7 (Table 3). This value was skewed upward by a few high pH values; the median pH value was 4.2. The pH of fresh refuse samples varied widely, while older weathered samples were generally strongly to very strongly acidic.

The fresh refuse at site RRA had a near neutral pH, while the material from BMR had a pH of 4.2. This suggests that the pyrite in the latter sample had started to oxidize. Total-S values are also presented in Table 3. In general, these values are low and are within the range reported by others who have examined refuse in the East (Buttermore 1975, Williams 1976). There is an obvious relationship between total-S content, extractable Al content, and pH within the three age groups represented (Table 3), and in the sample set as a whole.

Fig. 1 Percent water held at 3 soil moisture tensions.

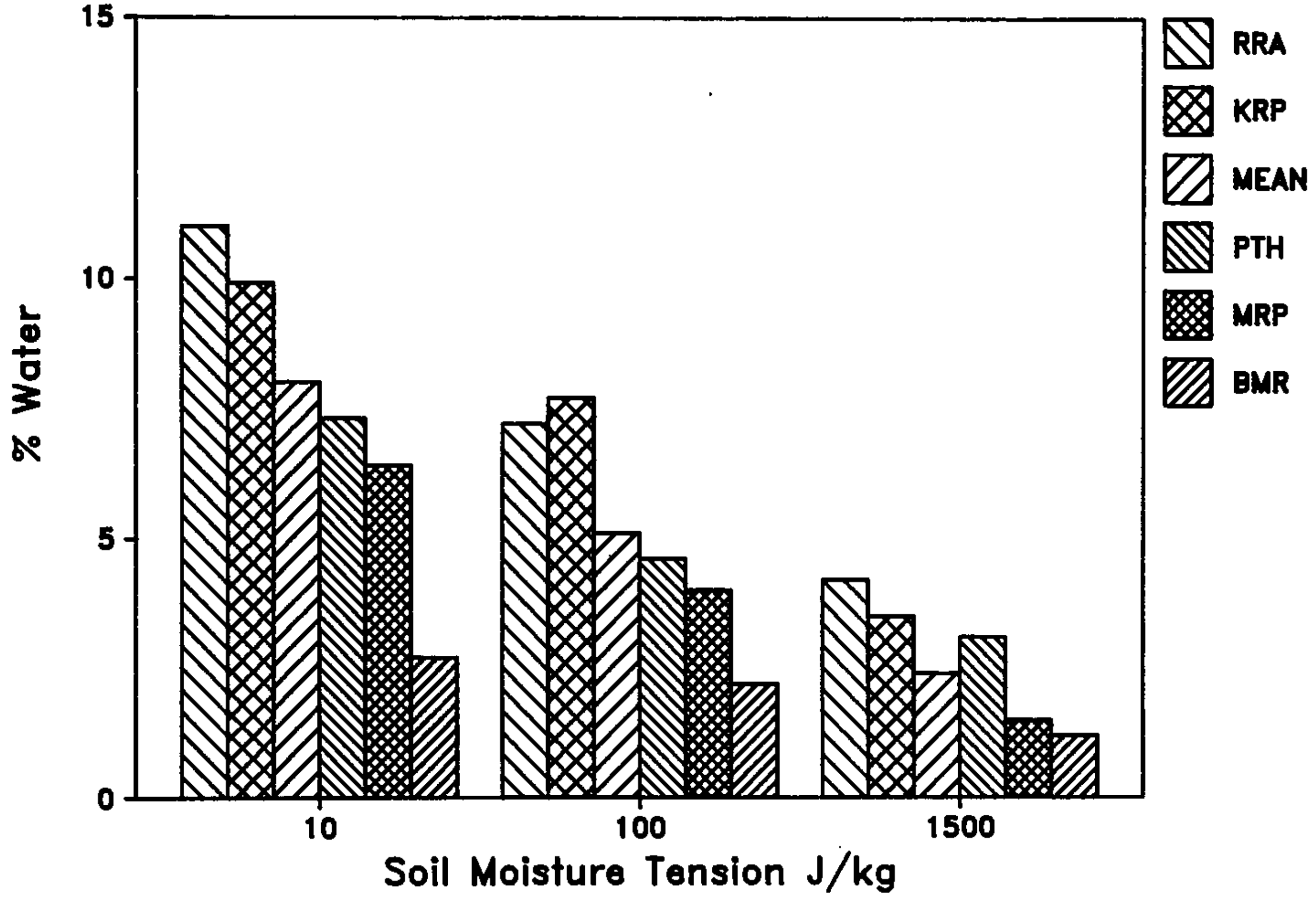

Table 3. The pH, cation exchange capacity (CEC), N KCl extractable Al, % base saturation, Total-S, and double acid extractable P for six selected sites and the 27 pile sample set mean.

Sample	pH	Conduct.	CEC	ext Al	% BS	% Tot-S
		dS/cm[*]	----cmol/kg----			
MRP	5.6	0.148	5.1	0.34	93.3	0.27
KRP	3.6	0.328	8.1	7.03	13.2	1.04
PTH	4.0	0.200	6.7	6.40	4.5	0.53
RRP	6.4	0.438	7.4	0.10	98.6	0.28
BMR	4.2	5.510	17.4[+]	1.36	92.0	1.43
RRA	7.1	3.580	7.9	0.20	97.5	0.54
Mean$^{(n=27)}$	4.7	0.923 [#@]	8.0	3.33	51.9	0.42

* deciSieman/cm.
\+ value affected by soluble salts
@ mean for 3 active piles 4.203 dS/cm.
\# mean for rest of sample set excluding active piles 0.496 dS/cm.

Table 4. Percent dithionite-citrate bicarbonate extractable Fe, percent total-Fe, and double acid extractable P of six selected sites and the 27 pile sample set mean.

Sample	% DCB ext Fe	% Tot. Fe	DA ext. P
			ppm
MRP	0.85	3.00	24.8
KRP	4.49	6.66	5.1
PTH	0.53	4.27	1.1
RRP	0.38	3.38	2.7
BMR	0.54	5.00	24.0
RRA	2.76	4.76	26.8
Mean$^{(n=27)}$	1.45	3.95	17.8

The piles with the higher sulfur contents have lower pH values and larger amounts of extractable Al. This is due to the acidity generated by pyrite oxidation, which attacks the alumino-silicate mineral structures and releases Al. The CEC values of these materials are generally low, and those piles with pH values <5 are heavily saturated with Al (Table 3). The exception to this trend is the BMR refuse which contains a large amount of soluble salts. The reported CEC and base saturation for BMR are probably high, due to soluble salt errors. The low CEC values in these materials results in a low nutrient holding capacity and the possibility of surface and ground water pollution through runoff.

Salt solutions used in coal cleaning, and the salts generated by acid sulfate weathering processes frequently lead to elevated levels of soluble salts in refuse materials. Electrical conductivity provides an indirect way to measure the amount of soluble salts in a material. Conductivities of > 2 dS/cm have been shown to be detrimental for the growth of some plants (Bower and Wilcox, 1965). The sample set mean conductivity is skewed upward, due to the high conductivities of the three active refuse piles in the sample set (Table 3). The mean for the three active piles is 4.2 dS/cm, while the mean for the 24 older piles is 0.49 dS/cm. The conductivity of the three active piles is above the 2 dS/cm value, which has been reported to be toxic to some plants. No other piles had a conductivity greater than 2.0 dS/cm. As fresh refuse weathers, many salts are generated, and with time these salts are leached. It may be beneficial to allow the conductivity to decrease through weathering and leaching before a reclamation effort is attempted.

An easily determined parameter that could be used to quantify the amount of weathering with time in refuse would be beneficial. "Free" (DCB extractable) Fe/total-Fe values were evaluated to see if this parameter correlated well with time. DCB-Fe and total-Fe data are presented in Table 4. The 27 pile sample set mean DCB-Fe:total-Fe ratio is 35%, however there is a large variation within the sample set. No clear relationship between DCB extractable Fe and total-Fe with time was observed. This could be due to the weatherability of different sizes of iron pyrite grains. Very fine grained pyrite will weather much faster than large grained pyrite (Caruccio, 1970).

There is a large amount of variability in the amount and availability of plant nutrients in coal refuse. This variability is illustrated by the nutrient P. The sample set mean of 17.9 ppm (Table 4) is skewed by a few very high values. The sample set median value is 7.6 ppm. Fourteen of the 27 samples extracted had double-acid-extractable-P values that fell into the low category on the plant availability index of Olsen and Dean (1965). One probable sink for P in refuse are Fe and Al phosphate compounds that form, especially in the more acidic materials. The wide variability in available P illustrates the need for testing of each pile instead of relying on a blanket recommendation for a region.

Conclusions

It appears that some refuse materials should be suitable for direct seeding if the proper surface amendments are applied. Adverse physical properties (low water holding capacity) must be addressed with amendments such as mulch or topsoil, if long-term reclamation success is to be achieved. In fresh refuse piles, sulfate salts may be a problem until oxidation slows and the salts are leached. Low pH and infertility can be rectified through liming and fertilization, but long-term nutrient retention and fixation problems are likely.

Variability of coal refuse properties, microclimate, and other soil/site conditions make the development of uniform reclamation strategies difficult. Reclamation planning is also further complicated by the fact that the physical and chemical properties of refuse will change considerably with time. An integrated refuse classification/ reclamation system is needed, along with dedicated trials to document the response of various types of refuse to various reclamation treatments.

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References

Barnhisel, R. I. and P. M. Bertsch. 1982. Aluminum. In A. L. Page (ed.), Methods of soil analysis, Part II, Agronomy 9:275-300.

Bernas, B. 1968. A new method for decomposition and comprehensive analysis of silicates by atomic absorbance spectrophotometry. Anal. Chem. 40:1682-1686.
http://dx.doi.org/10.1021/ac60267a017

Bland, A. E., and T. L. Robl, and J. G. Rose. 1977. Evaluation of interseam and coal cleaning effects on the chemical variability of past and present Kentucky coal refuse. Trans. AIME. 262:331-334.

Bower, C. A., and L. V. Wilcox. 1965. Soluble salts. In C. A. Black (ed.). Methods of soil analysis, Part II, Agronomy 9:933-951.

Buttermore, W. H., E. J. Simcoe, and M. A. Malloy. 1978. Characterization of coal refuse. Technical Report No. 159, Coal Research Bureau. West Virginia University, Morgantown, WV.

Caruccio, F. T. 1970. The quantification of reactive pyrite by grain size. In Reprints, Third Symposium on Coal Mine Drainage Research. Natl. Coal Aaan. and Bituminous Coal Research Inc.

Chapman, H. D. 1965. Cation-exchange capacity. In C. A. Black (ed.). Methods of soil analysis, Part II, Agronomy 9:891-901.

Day, P. R. 1965. Particle fractionation and particle size analysis. In C. A. Black (ed.). Methods of soil analysis, Part II, Agronomy 9:545-556.

Delp, C. H. 1975. Soil morphology characteristics, genesis and classification of West Virginia coal mine refuse. M. S. Thesis. West Virginia University. Morgantown, WV.

Holmgren, G. G. S. 1967. A rapid citrate-dithionite extractable iron procedure. Soil Sci. Soc. Amer. Proc.31:210-211. http://dx.doi.org/10.2136/sssaj1967.03615995003100020020x

Khan, L. A., S. B. Bhagwat, and J. W. Baxter. 1986. Economics of secondary recovery of coal. In Proceedings, 1986. Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation. University of Kentucky, Lexington, KY.

McClean, E. O. 1982. Soil pH and lime requirement. In C. A. Black (ed.). Methods of soil analysis, Part II, Agronomy 9:128-152.

Olsen, S. R. and L. A. Dean. 1965. Phosphorus. In C. A. Black (ed.). Methods of soil analysis, Part II, Agronomy 9:1035-1049.

Richards, L. A. 1965. Physical condition of water in soil. In C. A. Black (ed.). Methods of soil analysis, Part II, Agronomy 9:128-152.

Rhoades, J. D. 1982. Soluble salts. In A. L. Page (ed.), Methods of soil analysis, Part II, Agronomy 9:167-179.

Sencindiver, J. C. 1977. Classification and genesis of mine soils. Ph. D. diss. West Virginia University. Morgantown, WV.

Thomas, G. W. 1982. Exchangeable cations. In A. L. Page (ed.), Methods of soil analysis, Part II, Agronomy 9:167-179.